CHAPTER 2: ASSESSMENT OF THE PACIFIC COD STOCK IN THE EASTERN BERING SEA AND ALEUTIAN ISLANDS AREA

Grant G. Thompson and Martin W. Dorn

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center
7600 Sand Point Way NE., Seattle, WA 98115-0070

EXECUTIVE SUMMARY

Summary of Major Changes

Relative to the November edition of last year's BSAI SAFE report, the following substantive changes have been made in the Pacific cod stock assessment.

Changes in the Input Data

1) Catch data for 2003 were updated and preliminary catch data for 2004 were incorporated.
2) Size composition data from the 2003 commercial fisheries were updated and preliminary size composition data from the 2004 commercial fisheries were incorporated.
3) Size composition data from the 2004 EBS shelf bottom trawl survey were incorporated.
4) The biomass estimate from the 2004 EBS shelf bottom trawl survey was incorporated (the 2004 estimate of 596,988 t was down about 1% from the 2003 estimate) and minor corrections were made to the 2001-2003 estimates.
5) Age composition data from the 1998-2003 EBS shelf bottom trawl surveys were incorporated.
6) Length-at-age data from the 1998-2003 EBS shelf bottom trawl surveys were incorporated.
7) Size composition data from the 2002/2004 EBS slope bottom trawl surveys were incorporated.
8) Biomass estimates from the 2002/2004 EBS slope bottom trawl surveys were incorporated.
9) The biomass estimate from the 2004 Aleutian Islands bottom trawl survey was incorporated into the time series used to estimate the distribution of biomass between the EBS and AI.

Changes in the Assessment Model

No changes were made in the way population dynamics are represented in the assessment model. However, the incorporation of several new data sets (#5-8 above) necessitated the addition of likelihood components corresponding to each.

Changes in Assessment Results

1) The estimated 2005 female spawning biomass for the BSAI stock is 295,000 t, down about 32% from last year’s estimate for 2004 and down about 34% from last year's F_{ABC} projection for 2005.
2) The estimated 2005 total age 3+ biomass for the BSAI stock is 1,290,000 t, down about 22% from last year’s estimate for 2004 and down about 21% from last year's $F_{40\%}$ projection for 2005.
3) The recommended 2005 ABC for the BSAI stock is 206,000 t, down about 8% from last year’s estimate for 2004 and down about 8% from last year's F_{ABC} projection for 2005.
4) The estimated 2005 OFL for the BSAI stock is 265,000 t, down about 24% from last year's

estimate for 2004.

Responses to Comments of the Scientific and Statistical Committee (SSC)

SSC Comments Specific to the Pacific Cod Assessments

From the December, 2003 minutes: *"As recommended by the plan team and as noted by the SSC in their minutes last year, a comparison of slope and shelf survey length composition data may provide insight into the reliability of the domeshaped selectivity curve used in the model. Inclusion of new age data into the assessment is very worthwhile, as proposed by the team and author."* Age composition and length-at-age data from the 1998-2003 EBS shelf bottom trawl surveys and biomass and size composition data from the 2002 and 2004 EBS slope bottom trawl surveys have been incorporated into the model, as discussed in the "Data," "Analytic Approach," and "Model Evaluation"sections.

Also from the December, 2003 minutes: *"The ABC for BS/AI cod is not currently allocated by area. If the ABC were apportioned by the same multiplier used to expand the EBS assessment to the full BS/AI area, the ABC would be 191,000 mt and 32,000 mt for the EBS and AI areas, respectively. The team and authors were concerned that this apportionment may have implications on cod fishery management and allocation. The SSC believes that the ABC should be split among BS and AI areas, but we are not in a position to address the concerns expressed by the authors. Therefore, for the 2005 specification process, the SSC requests the authors to evaluate the methods used to split the ABC and their potential management implications, so that specific recommendations can be made to the Council on this issue in the future."* A comparison of methods for biomass-based apportionment of ABC among areas was presented in this year's preliminary SAFE report.

From the October, 2004 minutes: *"Grant Thompson, AFSC, presented different weighting schemes to estimate the distribution of Pacific cod biomass between the Aleutian Islands and the Bering Sea as requested by the SSC (December 2003 minutes). Although such weighting may no longer be necessary if a new, spatially disaggregated model is adopted for Pacific cod in the future, the SSC recommends using a weighting approach to estimate biomass distributions in the interim. Specifically, the SSC recommends the Kalman filter approach to estimate current biomass because it has a strong theoretical justification and appeared to result in sensible weights, with the most recent survey estimates receiving the highest weight. The SSC advises against an approach that uses relatively large weights on the initial survey year, such as those resulting from exponential weighting with a small* p *parameter."* The comparison of methods presented in this year's preliminary SAFE report (see response to preceding comment) was updated with results from the 2004 EBS shelf and AI bottom trawl surveys in Attachment 2A. Results from the Kalman filter approach are used to scale results from the EBS assessment model into BSAI-wide totals, as discussed in the "Survey Data" subsection of the "Data" section.

SSC Comments on Assessments in General

From the December, 2003 minutes: *"The SSC is encouraged that several assessment authors are investigating spawner-recruit relationships in their assessments (e.g., Pacific cod, several BSAI flatfish). This raises the possibility that some assessments can move up to Tier 1 from Tier 3 and thus more fully consider stock productivity. The SSC encourages investigations of this type while recognizing some difficulties. In particular, there may be some confounding of environmental effects with density dependence in the time series. For example, many flatfish stocks had low biomass during the 1970s and early 1980s and then increased dramatically. The resultant spawner-recruit curves consist of data points on the left side of the graph from the early period and on the right side of the graph from the most recent period. Nevertheless, authors could explore alternative spawner-recruit analyses based on subsets of the data and contrast those with an analysis using all of the data."* Alternative stock-recruitment curves based on pre-1989 and post-1988 subsets of the data are compared and contrasted with an estimated curve using all of the data in the "Recruitment" subsection of the "Results" section. In addition, correlations between recruitment and the Pacific Decadal Oscillation are presented in the "Ecosystem Effects on the Stock" subsection of the "Ecosystem Considerations" section.

Also from the December, 2003 minutes: "*Variation in distribution or productivity of a species at the periphery of its range has different management implications than variation of a similar magnitude at the center of the range. At the periphery of a species range, small variations in the natural environment may exceed the tolerance of the species and cause large rapid changes in local population size and distribution. In contrast, changes of similar magnitude in the center of the species range may be within the limits of tolerance of the species and therefore may result in little or no change in productivity. Recognizing the above relationships, the SSC recommends that, where possible, the assessment teams differentiate stocks or portions of stocks at the periphery of their ranges.*" Pacific cod in the Gulf of Alaska is not at the periphery of its range, as discussed in the "Introduction" section.

INTRODUCTION

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, occurring at depths from shoreline to 500 m. The southern limit of the species' distribution is about 34° N latitude, with a northern limit of about 63° N latitude. Pacific cod is distributed widely over the eastern Bering Sea (EBS) as well as in the Aleutian Islands (AI) area. The resource in these two areas (BSAI) is managed as a single unit. Tagging studies (e.g., Shimada and Kimura 1994) have demonstrated significant migration both within and between the EBS, AI, and Gulf of Alaska (GOA), and genetic studies (e.g., Grant et al. 1987) have failed to show significant evidence of stock structure within these areas. Pacific cod is not known to exhibit any special life history characteristics that would require it to be assessed or managed differently from other groundfish stocks in the EBS or AI areas.

FISHERY

During the early 1960s, a Japanese longline fishery harvested BSAI Pacific cod for the frozen fish market. Beginning in 1964, the Japanese trawl fishery for walleye pollock (*Theragra chalcogramma*) expanded and cod became an important bycatch species and an occasional target species when high concentrations were detected during pollock operations. By the time that the Magnuson Fishery Conservation and Management Act went into effect in 1977, foreign catches of Pacific cod had consistently been in the 30,000-70,000 t range for a full decade. Catches of Pacific cod taken in the EBS, AI, and BSAI since 1978 are shown in Tables 2.1a, 2.1b, and 2.1c, respectively. The catches in Tables 2.1a-c are broken down by management area, year, fleet sector, and gear type. In 1981, a U.S. domestic trawl fishery and several joint venture fisheries began operations in the BSAI. The foreign and joint venture sectors dominated catches through 1988, but by 1989 the domestic sector was dominant and by 1991 the foreign and joint venture sectors had been displaced entirely. Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components. Figure 2.1 shows areas in which sampled hauls for each of the three main gear types (trawl, longline, and pot) were concentrated during 2003. To create this figure, the EEZ off Alaska was divided into 20 km × 20 km squares. A square is shaded if more than two hauls containing Pacific cod were sampled in it during 2003.

The history of acceptable biological catch (ABC) and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate (i.e., all-gear, combined area) commercial catches in Table 2.2. From 1980 through 2004, TAC averaged about 77% of ABC, and aggregate commercial catch averaged about 88% of TAC. In 8 of these 25 years (32%), TAC equaled ABC exactly, and in 5 of these 25 years (20%), catch exceeded TAC (by an average of 4%). Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. For example, from 1980 through 2004, five different assessment models were used (Table 2.2), though the model remained almost entirely unchanged during the period 1997-2004 (except for the addition of a new fishery selectivity era beginning in 2000). Historically, the great majority of the BSAI catch has come from the EBS area. During the most recent complete five-year period (1999-2003), the EBS accounted for an average of about 83% of the BSAI catch.

Current regulations specify that the BSAI Pacific cod TAC will be allocated initially according to gear type as follows: the trawl fishery will be allocated 47%, the fixed gear (longline and pot) fishery will be allocated 51%, and the jig fishery will be allocated 2%; of the fixed gear allocation, the longline fishery will be allocated 80.3% (not counting catcher vessels less than 60 ft LOA), the pot fishery will be allocated 18.3% (not counting catcher vessels less than 60 ft. LOA), and fixed-gear catcher vessels less than 60 ft. LOA will be allocated 1.4%. Typically, as the harvest year progresses, it becomes apparent that one or more gear types will be unable to harvest their full allotment(s) by the end of the year. This is addressed by reallocating TAC between gear types in September of each year. Most often, such reallocations shift TAC from the trawl, jig, and sometimes pot components of the fishery to the longline catcher/processors. The longline catcher-processors typically receive 15,000-20,000 t per year through such transfers.

The catches shown in Tables 2.1a-c and 2.2 include estimated discards. Discard rates of Pacific cod in the various EBS and AI target fisheries are shown for each year 1991-2003 in Table 2.3.

DATA

This section describes data used in the current assessment. It does not attempt to summarize all available data pertaining to Pacific cod in the BSAI.

Commercial Catch Data

Catch Biomass

Catches (including estimated discards) taken in the EBS since 1978 are shown in Table 2.4, broken down by the three main gear types and intra-annual periods consisting of the months January-May, June-August, and September-December. This particular division, which was suggested by participants in the EBS fishery, is intended to reflect actual intra-annual differences in fleet operation (e.g., fishing operations during the spawning period may be different than at other times of year). In years for which estimates of the distribution by gear or period were not available, proxies based on other years' distributions were used.

Catch Size Composition

Fishery size compositions are presently available, by gear, for the years 1978 through the first part of 2004. As in all assessments since 1997, size composition data from trawl catches sampled on shore were not included in the set of input data, because a comparison of cruises for which both at-sea and shoreside size composition samples were available showed that, in the case of trawl catches, the shoreside data typically contained a smaller proportion of small fish than the at-sea data, indicating that these data may reflect post-discard landings rather than the entire catch. For ease of representation and analysis, length frequency data for Pacific cod can usefully be grouped according to the following set of 25 intervals or "bins," with the upper and lower boundaries shown in cm:

Bin Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Lower Bound:	9	12	15	18	21	24	27	30	33	36	39	42	45	50	55	60	65	70	75	80	85	90	95	100	105
Upper Bound:	11	14	17	20	23	26	29	32	35	38	41	44	49	54	59	64	69	74	79	84	89	94	99	104	115

Total length sample sizes for each year, gear, and period are shown in Table 2.5. The collections of relative length frequencies are shown by year, period, and size bin for the pre-1989 trawl fishery in Table 2.6, the pre-1989 longline fishery in Table 2.7, the post-1988 trawl fishery in Tables 2.8a-b, the post-1988 longline fishery in Tables 2.9a-b, and the pot fishery in Tables 2.10a-b.

Survey Data

EBS Shelf Bottom Trawl Survey

The relative size compositions from bottom trawl surveys of the EBS shelf conducted by the Alaska Fisheries Science Center since 1979 are shown in Table 2.11a, using the same length bins defined above for the commercial catch size compositions. Information regarding the absolute numbers of fish measured at each length are available only for the years 1986-1987 and 1990-2004. For all other years, only relative numbers of measured fish are available. The total sample sizes from the years 1986-1987 and 1990-2004 are shown below:

Year:	1986	1987	1990	1991	1992	1993	1994	1995	1996
Sample Size:	15376	10609	5628	7228	9601	10404	13922	9216	9348

Year:	1997	1998	1999	2000	2001	2002	2003	2004
Sample Size:	9169	9583	11699	12564	19750	12238	12360	10800

Following a decade-long hiatus in production ageing of Pacific cod, the Age and Growth Unit of the Alaska Fisheries Science Center recently began ageing samples of Pacific cod from the EBS shelf bottom trawl surveys (Roberson 2001). To date, the otolith collections from the 1998-2003 surveys have been read. The relative age compositions from these surveys are shown in Table 2.11b. The number of fish aged in each of these years is shown below:

Year:	1998	1999	2000	2001	2002	2003
Sample Size:	635	860	864	950	947	1360

Estimates of total abundance (both in biomass and numbers of fish) obtained from the trawl surveys are shown in Table 2.12, together with the standard errors and upper and lower 95% confidence intervals (CI) for the biomass estimates (the 2001-2003 estimates were recompiled this year and may be slightly different from values shown in previous assessments). Survey results indicate that biomass increased steadily from 1978 through 1983, then remained relatively constant from 1983 through 1989. The highest biomass ever observed by the survey was the 1994 estimate of 1,368,109 t. Following the high observation in 1994, the survey biomass estimate declined steadily through 1998. The survey biomass estimates have remained in the 525,000-625,000 t range from 1997 through 2004, except for 2001, when the estimate was 830,479 t. The 2004 estimate was 596,988 t.

In terms of numbers (as opposed to biomass), the record high was observed in 1979, when the population was estimated to include over 1.5 billion fish. The 1994 estimate of population numbers was the second highest on record. After the peak in 1994, numerical declines were observed through 1997, paralleling the biomass time trend. The survey estimate of population numbers remained in the 480-570 million fish range from 1997 through the present, except for 2001, when the estimate was 980 million fish, and 2004, when the estimate was 424 million fish.

Both the biomass and numerical abundance estimates from the 2001 survey appear likely to be overestimates, given the magnitudes of the implied increases relative to the 2000 survey (57% and 104%, respectively) and the fact that the 2002-2004 estimates were much closer to the preceding estimates.

EBS Slope Bottom Trawl Survey

The Alaska Fisheries Science Center conducted bottom trawl surveys of the EBS slope in 2002 and 2004. The relative size compositions from these surveys are shown in Table 2.11c, using the same length bins defined above for the commercial catch size compositions. A total of 468 fish were measured in the 2002 survey and a total of 531 fish were measured in the 2004 survey (note that these sample sizes are only about one-twentieth of the average sample size from the shelf survey). The biomass estimates and standard errors from the 2002 and 2004 surveys are shown below (all figures are in t):

Year	Biomass	Standard Error
2002	7511	1944
2004	5756	968

Aleutian Bottom Trawl Survey

Biomass estimates for the Aleutian Islands region were derived from U.S.-Japan cooperative trawl surveys conducted during the summers of 1980, 1983, and 1986, and by U.S. trawl surveys of the same area in 1991, 1994, 1997, 2000, 2002, and 2004. These surveys covered both the Aleutian management area (170 degrees east to 170 degrees west) and a portion of the Bering Sea management area ("Southern Bering Sea") not covered by the EBS shelf surveys. The time series of biomass estimates from both portions of the Aleutian survey area are shown together with their sum below (all figures are in t; results from the U.S.-Japan cooperative surveys are shown above the dashed line and results from the U.S.-only surveys are shown below the dashed line):

Year	Aleutian Management Area	Southern Bering Sea	Aleutian Survey Area
1980	52,070	74,373	126,443
1983	113,148	45,624	158,772
1986	172,625	42,298	214,923
1991	180,904	8,286	189,190
1994	153,026	31,084	184,109
1997	72,674	10,742	83,416
2000	126,918	9,157	136,075
2002	73,252	9,601	82,853
2004	82,432	31,964	114,396

In previous assessments of Pacific cod in the BSAI, a weighted average formed from EBS and Aleutian survey biomass estimates was used to provide a conversion factor which was used to translate model projections of EBS catch and biomass into BSAI equivalents. Because the assessment model is configured to represent the portion of the Pacific cod population inhabiting the EBS survey area (as opposed to the more extensive EBS *management* area), the biomass estimates from the entire Aleutian survey area (as opposed to the less extensive Aleutian *management* area) were used to inflate model projections of EBS catch and biomass. The weighted average used in previous assessments was computed from the sums of the biomass estimates from the EBS shelf and AI survey biomass time series.

However, in December of 2003 the SSC requested that alternative methods of estimating relative biomass between the EBS and AI be explored. Following a presentation of some possible alternatives in this year's preliminary SAFE report, the SSC recommended that an approach based on a simple Kalman filter be used (SSC Minutes, October, 2004). Attachment 2A provides an update of the methods and results presented in this year's preliminary SAFE report, incorporating new results from the 2004 EBS and AI bottom trawl surveys. Using the Kalman filter approach, the best estimate of the long-term average biomass distribution is 85% EBS and 15% AI, which also turns out to be the best estimate of the current biomass distribution. Coincidentally, this is identical to the biomass distribution estimated in last year's assessment (Thompson and Dorn 2003). Because the 83-112 net (with no roller gear) used in the EBS survey generally tends the bottom better than the polyethylene Noreastern net (with roller gear) used in the AI survey, this ratio should tend to err on the conservative side (that is, the AI survey would be expected to miss more fish than the EBS survey, so the true portion in the AI should be higher than the ratio of the AI to AI+EBS survey estimates).

Length at Age, Weight at Length, and Maturity at Length

The set of reliable length at age data for BSAI Pacific cod has been small for the past several years and such data were used only sparingly in the last several assessments. When production ageing of Pacific cod ended in the early 1990s, length at age data were available from samples taken during the 1988-1992 EBS bottom trawl shelf surveys. These data provided the following relationship between age and length and the amount of spread around that relationship (lengths, in cm, were measured during summer, and ages are back-dated to January 1):

Age group:	1	2	3	4	5	6	7	8	9	10	11	12
Average length:	19	29	37	48	57	65	73	79	82	84	86	89
St. dev. of length:	3.5	5.3	5.0	4.9	4.2	3.7	4.0	5.4	7.4	5.8	7.4	7.7

However, as noted in the "Survey Data" subsection above, production ageing of Pacific cod has recently begun again, and length at age data are now available from the 1998-2003 surveys. These data provided the following relationship between age and length and the amount of spread around that relationship (lengths, in cm, were measured during summer, and ages are back-dated to January 1):

Age group:	1	2	3	4	5	6	7	8	9	10	11	12
Average length:	17	29	39	48	57	65	71	77	82	82	88	95
St. dev. of length:	3.5	4.0	4.5	4.7	5.8	6.2	7.2	8.5	9.9	9.2	10.6	3.3

Although the standard deviations of length at age are somewhat different, the mean lengths at age are very similar between the two data sets (note that sample size tends to be small for the oldest ages).

Weight measurements taken during summer bottom trawl surveys since 1975 yield the following data regarding average weights (in kg) at length, grouped according to size composition bin (as defined under "Catch Size Composition" above):

Bin Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ave. weight:	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.6	0.7	0.9	1.2	1.6	2.2	2.9	3.5	4.6	5.6	7.0	8.4	10.1	11.8	11.0	15.0

The past several assessments have used a maturity schedule based on a sampling program conducted in 1993-1994, using commercial fishery observers. The data consisted of observers' visual determinations regarding the spawning condition of 2312 females taken in the EBS fishery. Of these 2312 females, 231 were smaller than 42 cm (the lower boundary of length bin 12). None of these sub-42 cm fish were mature. The observed proportions of mature fish in the remaining length bins, together with the numbers of fish sampled in those length bins, are shown below (bins are defined under "Catch Size Composition" above):

Bin number:	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Prop. mature:	0.03	0.05	0.14	0.19	0.28	0.53	0.69	0.82	0.89	0.94	0.94	0.91	0.89	1.00
Sample size:	39	122	226	313	295	300	320	177	103	70	50	35	19	12

ANALYTIC APPROACH

Model Structure

This year's base model is identical to the model used in the 2002 and 2003 assessments, which in turn was identical to the model used in the 1997-2001 assessments except for the addition of a new commercial selectivity era beginning in 2000 (Thompson and Dorn 2002). Beginning with the 1993 SAFE report (Thompson and Methot 1993), a length-structured Synthesis model (Methot 1986, 1990, 1998, 2000) has formed the primary analytical tool used to assess the EBS Pacific cod stock. Synthesis is a program that uses the parameters of a set of equations governing the assumed dynamics of the stock (the "model parameters") as surrogates for the parameters of statistical distributions from which the data are assumed to be drawn (the "distribution parameters"), and varies the model parameters systematically in the direction of increasing likelihood until a maximum is reached. The overall likelihood is the product of the likelihoods for each of the model components. Each likelihood component is associated with a set of data assumed to be drawn from statistical distributions of the same general form (e.g., multinomial, lognormal, etc.). Typically, likelihood components are associated with data sets such as catch size (or age) composition, survey size (or age) composition, and survey biomass.

The Synthesis program permits each data time series to be divided into multiple segments, or "eras," resulting in a separate set of parameter estimates for each era. In the base model for the EBS Pacific cod assessment, for example, the survey size composition and survey biomass time series have traditionally been split into pre-1982 and post-1981 eras to account for the effects of a change in the trawl survey gear that occurred in 1982. Also, to account for possible differences in selectivity between the mostly foreign (also joint venture) and mostly domestic fisheries, the fishery size composition time series in the base model has traditionally been split into pre-1989 and post-1988 eras. A minor modification of the base model was suggested by the SSC in 2001, namely, that consideration be given to dividing the domestic era into pre-2000 and post-1999 segments. This modification was tested in the 2002 assessment (Thompson and Dorn 2002) and was found to result in a statistically significant improvement in the model's ability to fit the data.

Symbols used in the base model are listed in Table 2.13 (note that this list applies to the stock assessment model only, and does not include all symbols used elsewhere in this document). Full documentation of the equations used in Synthesis was given by Methot (2000) and functional representations of population dynamics using the notation of Table 2.13 were given in Appendix 2A of the 2002 stock assessment (Thompson et al. 2002). Synthesis uses a total of 16 dimensional constants, special values of indices, and special values of continuous variables, all of which are listed on the first page of Table 2.13. The values of these quantities are not estimated statistically, in the strict sense, but are typically set by assumption or as a matter of structural specification. The values of these constants, indices, and variables are listed in Table 2.14, with a brief rationale given for each value used. In contrast to the quantities whose values are specified in Table 2.14, Synthesis uses a large number of parameters that are estimated statistically (though the estimation itself may not necessarily take place within Synthesis). For ease of reference, capital Roman letters are used to designate such "Synthesis parameters," which are listed on the second page of Table 2.13.

In this year's assessment, an alternative to the base model is presented. "Model 1" denotes the base model and "Model 2" denotes the alternative model. Model 2 is identical to Model 1 in terms of the way population dynamics are represented. However, Model 2 estimates a set of selectivity parameters for the EBS slope bottom trawl survey and adds new likelihood components for the age composition and length-at-age data from the 1998-2003 EBS shelf bottom trawl surveys and the size composition and biomass data from the 2002/2004 EBS slope bottom trawl surveys. The SSC suggested incorporating age data and slope survey data into the model (SSC minutes, December, 2003). It should be noted that Model 2 uses some parameters not used in Model 1, so Table 2.13 does not constitute a complete list of parameters in the case of Model 2. When a parameter is unique to Model 2, it is identified as such in the next two subsections. Generally, these are analogous to counterparts in Model 1.

Parameters Estimated Independently

Table 2.15 divides the set of base model parameters into two parts, the first of which lists those parameters that were estimated independently (i.e., outside of Synthesis), and the second of which lists those parameters that were estimated conditionally (i.e., inside of Synthesis). This section describes the estimation of parameters in the first part of Table 2.15 (except that one ambiguity arises in the case of parameter L_1, the parameter representing length at age 1.5, which is estimated independently in Model 1 but conditionally in Model 2). It also describes the information of a few independently estimated parameters unique to Model 2.

<u>Natural Mortality</u>

The natural mortality rate was estimated independently of other parameters at a value of 0.37. This value was used in the present assessment for the following reasons: 1) it was derived as the maximum likelihood estimate of *M* in the 1993 BSAI Pacific cod assessment (Thompson and Methot 1993), 2) it has been used to represent *M* in all BSAI Pacific cod assessments since 1993 and in all GOA Pacific cod assessments except one since 1994, 3) it was explicitly accepted by the SSC for use as an estimate of *M* in the GOA Pacific cod assessment (SSC minutes, December, 1994), and 4) it lies well within the range of previously published estimates of *M* shown below:

Area	Author	Year	Value
Eastern Bering Sea	Low	1974	0.30-0.45
	Wespestad et al.	1982	0.70
	Bakkala and Wespestad	1985	0.45
	Thompson and Shimada	1990	0.29
	Thompson and Methot	1993	0.37
Gulf of Alaska	Thompson and Zenger	1993	0.27
	Thompson and Zenger	1995	0.50
British Columbia	Ketchen	1964	0.83-0.99
	Fournier	1983	0.65

Trawl Survey Catchability

The base model used in the last several assessments has estimated the catchability coefficient for the EBS shelf bottom trawl survey independently of other parameters at a value of 1.0. Preliminary results of recent experimental work conducted in the EBS by the Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering Division tend to confirm that this is a reasonable value (Somerton 2004). A catchability coefficient of 1.0 for the EBS shelf bottom trawl survey is retained in Model 1 of the present assessment.

Following Wilderbuer and Sample (2003), the survey catchability coefficient for Model 2 was partitioned proportionately between the EBS shelf and slope, with the sum of the coefficients fixed at 1.0. Using a Kalman filter analysis similar to that described in Attachment 2A, the best estimate of the long-term average biomass distribution between the EBS shelf and slope is 0.992 shelf and 0.008 slope.

Weight at Length

Parameters (Table 2.13) governing the relationship between weight and length were estimated by log-log regression from the available data (see "Data" above), giving the following values (weights are in kg, lengths in cm): $W_1 = 4.36 \times 10^{-6}$, $W_2 = 3.242$.

Length at First Age of Survey Observation

Previous assessments assumed that the first age at which Pacific cod are seen in the trawl survey (α_1, Table 2.13) is approximately 1.5 years and estimated the length at this age (L_1, Table 2.13) by averaging the lengths corresponding to the first mode greater than or equal to 14 cm (bin 2) from each of the five most recent survey size compositions. The same approach was used in the present assessment for Model 1, giving an L_1 value of 16.6 cm.

Because one of the assumptions underlying the development of Model 2 is that recent survey age data are reliable, Model 2 estimates L_1 conditionally.

Variability in Length at Age

Previous assessments estimated the parameters (Table 2.13) governing the amount of variability surrounding the length-at-age relationship directly from the observed standard deviations in the then-available (1988-1992) length-at-age data (see "Data" above), giving the following values (in cm): $X_1 = 3.5$, $X_2 = 7.7$. The same estimates are used for Model 1 in the present assessment. Estimation of these two parameters constituted the only use of age data in previous assessments and in Model 1 of the present assessment.

Model 2 estimated a schedule of standard deviations from the new (1998-2003) length-at-age data (see "Data" above) using weighted least squares regression to fit a linear relationship, giving the following values (in cm): $X_1 = 3.4$, $X_2 = 9.5$.

Percent Agreement Between Age Readers

Model 2 requires estimates of the schedule of percent agreement ("PA") between age readers. Weighted least squares regression was used to fit an exponential relationship to the available data (total sample size = 2,256), giving the following schedule (no data are available for age 12):

Age:	1	2	3	4	5	6	7	8	9	10	11	12
Mean PA:	0.929	0.743	0.613	0.556	0.466	0.400	0.356	0.288	0.333	0.333	0.250	n/a
Std. Error:	0.014	0.024	0.025	0.025	0.026	0.032	0.044	0.059	0.122	0.157	0.217	n/a
Regression:	0.900	0.767	0.654	0.557	0.475	0.405	0.345	0.294	0.250	0.213	0.182	0.155

Model 1 does not use age data and therefore does not need estimates of percent agreement.

Maturity at Length

Maximum likelihood estimates of the parameters (Table 2.13) governing the female maturity-at-length schedule were obtained using the method described by Prentice (1976), giving the following values: P_1 = 0.142, P_2 = 67.1 cm. The variance-covariance matrix of the parameter estimates gave a standard deviation of 0.006 for the estimate of P_1, a standard deviation of 0.39 cm for the estimate of P_2, and a correlation of -0.154 between the estimates of the two parameters.

Parameters Estimated Conditionally

Base model parameters that are estimated internally are listed in the second part of Table 2.15. In addition, the parameter representing length at age 1.5 and seven parameters defining the EBS slope bottom trawl selectivity schedule are estimated conditionally in Model 2 (and not used at all in Model 1). The estimates of all these parameters are conditional on each other, as well as on those listed in the first part of the table and discussed in the preceding section (i.e., the parameters that are estimated independently).

Likelihood Components

As noted in the "Model Structure" section, Synthesis is a likelihood-based framework for parameter estimation which allows several data components to be considered simultaneously. As in previous assessments, four fishery size composition likelihood components were included in both Model 1 and Model 2: the January-May ("early") trawl fishery, the June-December ("late") trawl fishery, the longline fishery, and the pot fishery. Also corresponding to the structure of previous assessment models, both Model 1 and Model 2 included likelihood components for the size composition and biomass trend from the EBS shelf bottom trawl survey.

In addition to the above likelihood components common to both models, Model 2 introduced four new likelihood components corresponding to the four new data types: 1) 1998-2003 EBS shelf bottom trawl age compositions, 2) 1998-2003 EBS shelf bottom trawl survey mean length-at-age estimates, 3) 2002/2004 EBS slope bottom trawl survey size compositions, and 4) 2002/2004 EBS slope bottom trawl survey biomass estimates.

The Synthesis program allows the modeler to specify "emphasis" factors that determine which components receive the greatest attention during the parameter estimation process. As in previous assessments, each component in each model was given an emphasis of 1.0 in the present assessment.

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear/fishery, and time period within the year. In the parameter estimation process, Synthesis weights a given size composition observation (i.e., the size frequency distribution observed in a given year, gear/fishery, and period) according to the emphasis associated with the respective likelihood component and the sample size specified for the multinomial distribution from which the data are assumed to be drawn. In developing the model upon which Synthesis was originally based, Fournier and Archibald (1982) suggested truncating the multinomial sample size at a value of 400 in order to compensate for contingencies which cause the sampling process to depart from the process that gives rise to the multinomial distribution. As in previous assessments, the present assessment uses a multinomial sample size equal to the square root of the true length sample size, rather than the true length sample size itself. Given the true length sample sizes observed in the present assessment, this procedure tends to give values somewhat below 400 while still providing the Synthesis program with usable information regarding the appropriate effort to devote to fitting individual length samples. Multinomial length sample sizes derived by this procedure for the commercial fishery size compositions are shown in Table 2.16. In the case of EBS shelf bottom trawl survey size composition data, the square root assumption was also used, except that it was necessary to assume a true length sample size for the years 1979-1985 and 1988-1989, years for which such measures are unavailable (see “Trawl Survey Data” above). For those years, a true length sample size of 10,000 fish was assumed (giving a multinomial sample size of 100), which approximates the average of the 10 known true length sample sizes from the years 1986-1997. For the years 1986-1987 and 1990-2004, the square roots (SR) of the true survey length sample sizes are shown below:

Year:	1986	1987	1990	1991	1992	1993	1994	1995	1996
SR(sample size):	124	103	75	85	98	102	118	96	97

Year:	1997	1998	1999	2000	2001	2002	2003	2004
SR(sample size):	96	98	108	112	141	111	111	104

For the 2002 and 2004 EBS slope bottom trawl surveys, the true length sample sizes and square roots are shown below (used only in Model 2):

Year:	2002	2004
True length sample size:	468	531
SR(sample size):	22	23

Use of Age Composition Data in Parameter Estimation

Age composition data are not used in Model 1. Model 2, however, contains two likelihood components involving age data. These components correspond to the age composition and mean length-at-age data from the 1998-2003 EBS shelf bottom trawl surveys. Like the size composition data, the age composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear/fishery (in this case, the EBS shelf bottom trawl survey), and time period within the year (in this case, period 2). However, selection of an appropriate input sample size is more complicated for age composition data than for length composition data, because age composition data are generated not only from the set of otolith readings but from the estimated size composition as well. Therefore, even if a square root transformation is appropriate for size composition data, taking the square root of the number of otoliths read may underestimate the weight that should be given to the age composition data. Instead, a method similar to that advocated by Barbeaux et al. (this volume) was used to compute an appropriate input sample size for age composition data in Model 2. The steps were as follow:

1) The proportions of age at length are assumed to be approximately multivariate normally distributed, with a variance-covariance matrix determined by the matrix of proportions and the number of otoliths actually read at each length. A set of 1,000 random age-length keys was then simulated.

2) Survey numbers at each length are assumed to be approximately lognormally distributed with a mean equal to the point estimate and for that length and a constant (across lengths) coefficient of variation (CV) equal to the amount that sets the sum of the variances in numbers at length equal to the variance of the survey estimate of population size. A set 1,000 of random numbers-at-length distributions was then simulated.

3) For each combination of randomly simulated age-key and numbers-at-length distribution, an effective sample size was computed.

4) The “true” input sample size was set equal to the harmonic mean of the distribution of randomly simulated effective sample sizes, based on the asymptotic equivalence of these two quantities. The following table was thereby obtained for the age composition data (the last row shows the values used as “true” input sample sizes for Model 2):

Year	1998	1999	2000	2001	2002	2003
Number of fish aged:	635	860	864	950	947	1360
Square root of number of fish aged:	25	29	29	31	31	37
CV of numbers at length:	0.55	0.60	0.72	0.63	0.65	0.87
Harmonic mean effective sample size:	97	130	102	108	109	76

Note that this procedure gives an input sample size larger than would be achieved simply by taking the square root fo the number of fish aged (third row in the above table). This reflects the added precision achieved by use of both age-at-length and numbers-at-length data in constructing a numbers-at-age estimate. To avoid double counting of the same data, Model 2 does not make direct use of length composition data from the 1998-2003 EBS shelf bottom trawl surveys.

It may be noted that all but one of the harmonic mean effective sample sizes computed above is smaller (though only slightly so) than the sample sizes obtained for the corresponding length compositions using the "square root method" in the preceding subsection, suggesting that the two methods of computing sample sizes are not entirely consistent. This is not surprising, given that the square root method was adopted only as a simple approximation in the first place, but it does suggest a need for further work in this area.

Use of Size-at-Age Data in Parameter Estimation

Model 2 uses size at age data; Model 1 does not. In Model 2, each size at age datum is assumed to be drawn from a normal distribution specific for that age and year. The model's estimate of mean size at age serves as the mean for that year's distribution, and the standard deviation is inversely proportional to the sample size (Methot 2000). The following mean lengths (cm) at age were used for the length-at-age likelihood component (n/a indicates no samples were taken at that age and year combination):

Year	1	2	3	4	5	6	7	8	9	10	11	12
1998	15	31	38	49	59	67	70	77	90	n/a	94	n/a
1999	16	30	40	46	57	65	71	78	77	n/a	88	n/a
2000	15	30	38	48	54	59	70	70	78	79	70	n/a
2001	18	31	37	48	56	62	65	74	74	70	87	91
2002	17	30	37	47	55	63	68	70	75	93	n/a	95
2003	18	30	41	48	57	65	71	75	82	78	79	n/a

The following length-at-age sample sizes were also used for the length-at-age likelihood component:

Year	1	2	3	4	5	6	7	8	9	10	11	12
1998	56	145	97	94	73	88	47	28	6	n/a	1	n/a
1999	84	167	195	162	105	77	44	17	8	n/a	1	n/a
2000	112	102	131	204	177	83	21	20	7	6	1	n/a
2001	173	161	159	135	127	119	43	15	7	4	5	1
2002	114	165	206	189	85	91	70	16	6	2	n/a	2
2003	193	222	205	198	206	129	114	68	17	1	4	n/a

Use of Survey Biomass Data in Parameter Estimation

Each year's survey biomass datum is assumed to be drawn from a lognormal distribution specific to that year. The model's estimate of survey biomass in a given year serves as the geometric mean for that year's lognormal distribution, and the ratio of the survey biomass datum's standard error to the survey biomass datum itself serves as the distribution's coefficient of variation.

The EBS shelf bottom trawl survey biomass estimates are used in both models; the EBS slope bottom trawl survey biomass estimates are used only in Model 2.

MODEL EVALUATION

As described in the preceding section, two alternative models are evaluated in the present assessment. Model 1 is the base model, identical to the model used in the 2002 and 2003 assessments, which in turn was identical to the model used in the 1997-2001 assessments except for the addition of a new commercial selectivity era beginning in 2000. Model 2 is identical to Model 1 in terms of the way population dynamics are represented. However, Model 2 estimates a set of selectivity parameters for the EBS slope bottom trawl survey and adds new likelihood components for the age composition and length-at-age data from the 1998-2003 EBS shelf bottom trawl surveys and the size composition and biomass data from the 2002/2004 EBS slope bottom trawl surveys.

Evaluation Criteria

Four criteria were used to evaluate the stock assessment model: 1) the effective sample sizes of the size and age composition data, 2) the root mean squared error (RMSE) of the fit to the survey biomass data, 3) the fit to the size at age data, and 4) the reasonableness of the estimated biomass time series.

Effective Sample Size

Once maximum likelihood estimates of the model parameters have been obtained, Synthesis computes an "effective" sample size for the size or age composition data specific to a particular year, gear/fishery, and time period within the year. Roughly, the effective sample size can be interpreted as the multinomial sample size that would typically be required in order to produce the given fit. More precisely, it is the sample size that sets the sum of the marginal variances of the proportions implied by the multinomial distribution equal to the sum of the squared differences between the sample proportions and the estimated proportions (McAllister and Ianelli 1997). As a function of a multinomial random variable, the effective sample size has its own distribution. The harmonic mean of the distribution is asymptotically equal to the true sample size in the multinomial distribution. Thus, if the effective sample size is less than the true sample size in the multinomial distribution, it is reasonable to conclude that the fit is not as good as expected. The following table shows the average of the input sample sizes and the average effective sample sizes for each of the size composition components in the two models (in each column, the average is computed with respect to all years and periods present in the respective time series):

	Model 1 (lengths only)			Model 2 (lengths and ages)		
Likelihood component (or portion)	Eff. N	Input N	Ratio	Eff. N	Input N	Ratio
Early-season trawl fishery length	233	193	1.21	199	193	1.03
Late-season trawl fishery length	90	47	1.90	105	47	2.21
Longline fishery length	313	195	1.61	327	195	1.68
Pot fishery length	234	108	2.17	208	108	1.93
1979-1981 shelf survey length	93	100	0.93	59	100	0.59
1982-1997, 2004 shelf surv. length	169	100	1.69	92	100	0.92
1998-2003 shelf survey length	218	114	1.92	78	1	n/a
Shelf survey age	n/a	n/a	n/a	40	104	0.39
Slope survey length	n/a	n/a	n/a	212	23	9.40

Both models produce average effective sample sizes larger than the average input values for all four commercial fishery length components. Within these four components, Model 1 produces higher values than Model 2 for the early-season trawl fishery and the pot fishery, while Model 2 produces higher values than Model 1 for the late-season trawl fishery and the longline fishery. Neither model produces an average effective sample size larger than the average input value for the 1979-1981 shelf survey length component; however, this outcome is not particularly meaningful because the true sample sizes for those years are unknown. Model 1 produces an average effective sample size larger than the average input value for the 1982-1997 and 2004 shelf survey length component, but Model 2 does not.

Note that only the first six rows of results in the above table are strictly comparable. The seventh row (“1998-2003 shelf survey length”) is split out from the previous row because the input sample size was set equal to unity in Model 2 to avoid double counting of these data. Model 1 tends to fit these data very well. Model 2 manages to produce an effective sample size of 78 even though these data are given only negligible weight in that model.

The last two rows of results pertain to likelihood components that were included in Model 2 but not in Model 1. For the shelf survey age compositions, Model 2 produces an average effective sample size that is considerably smaller than the average input size. Although the average effective sample size for the shelf survey age compositions in Model 2 is fairly low; this may be due more to inconsistency in the data themselves than to a shortcoming of the model. For example, the following matrix shows the correlations between the 1996-1999 year classes at comparable ages (e.g., if the 1996 year class at each age were 10% larger than the 1997 year class at the same age, the correlation would be 1.00):

	1996	1997	1998	1999
1996	1.00	0.89	-0.18	0.97
1997	0.89	1.00	0.45	0.63
1998	-0.18	0.45	1.00	-0.06
1999	0.97	0.63	-0.06	1.00

Of the six possible pairwise correlations in the above table, three are less than 50% and two of these are actually negative. It would probably be difficult for any model to fit such data very well.

For the 2002 and 2004 slope survey size composition, Model 2 produces an average effective sample size that is considerably larger than the average input sample size. However, it is not surprising that Model 2 would be able to fit only two years’ worth of size composition data fairly well using a seven-parameter selectivity function.

<u>Fit to Survey Biomass Data</u>

The root-mean-squared value of the lognormal "sigma" parameter in the shelf survey biomass data is 0.095. The log-scale RMSEs from Models 1 and 2 are 0.196 and 0.191, respectively. Although Model 2 performs slightly better than Model 1, both RMSEs are a little more than twice the value of the root-mean-squared-sigma. The inability of either model to achieve a log-scale RMSE close to the root-mean-squared-sigma may indicate that simple haul-to-haul sampling variability underestimates the true variability of the shelf survey biomass data.

For the slope survey biomass data (which consist of only two points), Model 2 produces a log-scale RMSE of 0.219, which is very close to the root-mean-squared sigma of 0.213. Model 1 does not attempt to estimate slope survey biomass.

Fit to Size at Age Data

Mean size at age from the 1998-2003 EBS shelf bottom trawl surveys ("Data") are compared below with results from Models 1 and 2:

Age:	1	2	3	4	5	6	7	8	9	10	11	12
Data:	17	29	39	48	57	65	71	77	82	82	88	95
Model 1:	17	34	47	57	66	73	79	83	87	90	93	96
Model 2:	14	28	40	50	59	66	73	78	83	87	90	96

The coefficients of determination for Models 1 and 2 are 0.92 and 0.99, respectively. Model 2 is closer to the data at all ages except age 1 (because Model 1 is forced to fit the average first size mode from the last five surveys, Model 1 would be expected to give a better fit at age 1). Although the discrepancy between Model 1 and the data may not appear excessive in terms of *size at age*, the discrepancy in terms of *age at size* is approximately 1 year for ages 4-9 (e.g., the average size at age 5 is 57 cm according to the data, but the same average size corresponds to age 4 in Model 1).

Reasonableness of Biomass Estimates

The time series of age 3+ biomass, spawning biomass, and survey biomass estimated by Models 1 and 2 are compared, along with the observed survey biomass time series, in Table 2.17. The past several assessments have tended to result in estimates of age 3+ biomass that were much greater than the survey biomass. Models 1 and 2 in the present assessment behave likewise, although the biomass estimates produced by Model 2 tend not to be as high as those produced by Model 1. On average, the estimates of age 3+ biomass exceed the observed survey biomass by about 110% in the case of Model 1 and 87% in the case of Model 2. While it is possible to imagine mechanisms that could cause the bottom trawl survey to underestimate the total biomass of Pacific cod (e.g., a large portion of the population occurring in the water column above the headrope), the existence of any such mechanism has yet to be verified experimentally. Until such time as the existence of such a mechanism can be verified, models which tend to fit the survey more closely should probably be preferred, all else being equal.

Selection of Final Model

Evaluation of Models 1 and 2 using the four criteria may be summarized as follows: 1) For the six likelihood components where input sample sizes were directly comparable, the average effective sample sizes showed mixed results between the two models, with Model 1 having a slight edge over Model 2. 2) The fit to the survey biomass data (i.e, estimated survey biomass versus actual survey biomass) was comparable between the two models, with Model 2 having a slight edge over Model 1. 3) The fit to the size at age data was distinctly better under Model 2 than Model 1. 4) Relative to the survey biomass time series, the estimated age 3+ biomass time series obtained under Model 2 was somewhat closer than was that obtained under Model 1. On balance, then, Model 2 appears to be the better choice.

Size compositions estimated by Model 2 for the January-May fisheries in 2002, 2003, and 2004 are compared against the observed size compositions in Figures 2.2, 2.3, and 2.4, respectively. Size compositions estimated by Model 2 for the three most recent bottom trawl surveys of the EBS shelf are compared against the observed size compositions in Figure 2.5a, observed and estimated size compositions from the 2002 and 2004 bottom trawl surveys of the EBS slope are compared in Figure 2.5b, and observed and estimated age compositions from the 1998-2003 bottom trawl surveys of the EBS shelf are compared in Figure 2.5c.

Schedules Defined by Parameter Estimates

Estimates of length-at-age parameters K, L_1, and L_2 obtained under Model 2 are shown below:

Parameter	Estimate
K	0.157
L_1	13.0
L_2	91.9

Model 2's estimates of fishing mortality rates $F_{g,y,i}$, recruitments R_y and initial numbers at age N_a , and selectivity parameters $S_{1\text{-}7,g,e(y|g)}$ are shown in Tables 2.18, 2.19, and 2.20, respectively.

The distribution of lengths at age (measured in mid-year) defined by the final parameter estimates is shown in Table 2.21.

Weights at length and maturity proportions at length defined by the final parameters are shown in Table 2.22, and selectivities at length defined by the final parameter estimates are shown in Tables 2.23a and 2.23b.

RESULTS

Definitions

The biomass estimates presented here will be defined in three ways: 1) age 3+ biomass, consisting of the biomass of all fish aged three years or greater in January of a given year; 2) spawning biomass, consisting of the biomass of all spawning females in March of a given year; and 3) survey biomass, consisting of the biomass of all fish that the model estimates should have been observed by the survey in July of a given year. The recruitment estimates presented here will be defined in two ways: 1) as numbers of age 3 fish in January of a given year and 2) as the recruitment parameter R_y, which represents numbers at age 1 in January of year y. The fishing mortality rates presented here will be defined as full-selection, instantaneous fishing mortality rates expressed on a per annum scale.

Biomass

The model's estimate of the recent history of the stock (EBS portion only) is shown in Table

2.24, together with estimates provided in last year's final SAFE report (Thompson and Dorn 2003). The biomass trends (age 3+, spawning, and survey) estimated in the present assessment are also shown in Figure 2.6. The model's estimated time series of "survey" biomass parallels the biomass trend from the actual survey reasonably well, particularly given the occasional volatility of the survey time series. The model's estimate of survey biomass is within two standard deviations of the survey point estimate in 19 out of 26 years (73%). Exceptions occur with respect to the 1985, 1991, and 1992 estimates, where the model's estimates are more than two standard deviations above the data, and with respect to the 1994, 1995, 1996, and 2001 estimates, where the model's estimates are more than two standard deviations below the data.

Figure 2.7 compares this year's estimate of the survey biomass time series with those from all other assessments since 1997 (the year in which the base model was standardized). These annual estimates have been remarkably consistent. If each assessment's estimate of the survey biomass time series had been used to predict the next assessment's estimate of the same time series, the R^2 would have ranged from a low of 0.971 (using the 2003 estimates to predict the 2004 estimates) to a high of 0.998 (using the 1998 estimates to predict the 1999 estimates and using the 2002 estimates to predict the 2003 estimates) . There is no obvious time trend in the survey biomass estimates between assessments, a result likely aided by the fact that the natural mortality rate has been fixed at a value of 0.37 and the catchability coefficient for the EBS shelf bottom trawl survey has been fixed at (or near) a value of 1.0 throughout these assessments.

The model's estimated age 3+ biomass shows a near-continual decline from 1987 through 2000, with some indication that the stock has turned the corner in the years since. The model's estimated spawning biomass shows a similar trend. Evidence of a recent upturn notwithstanding, the model's estimates of 2000-2004 spawning biomass are the five lowest points in the time series since 1981.

Figure 2.8 compares this year's estimate of the age 3+ biomass time series with those from all other assessments since 1997. Ignoring the present assessment for the moment, these annual estimates have been remarkably consistent. If each assessment's estimate of the age 3+ biomass time series had been used to predict the next assessment's estimate of the same time series, the R^2 would have ranged from a low of 0.942 (using the 1998 estimates to predict the 1999 estimates) to a high of 0.999 (using the 2002 estimates to predict the 2003 estimates). However, using the 2003 estimates to predict the 2004 estimates results in an R^2 of only 0.736, due to the addition of several new data types. To examine whether the results show a consistent retrospective bias, the relative change in each year's age 3+ biomass estimate as assessed between each pair of successive assessments was computed (e.g., the relative change in the estimated value of age 3+ biomass for 1985 as assessed in, say, the 2000 and 2001 assessments), then the relative changes were averaged for each pair of successive assessments. The average relative change between the 1997 and 1998 assessments was negative, but for all other pairs of successive assessments the average relative change was either zero or slightly positive, as shown in the table below:

First assessment year	1997	1998	1999	2000	2001	2002	2003
Second assessment year	1998	1999	2000	2001	2002	2003	2004
Average relative change in age 3+ biomass	-0.033	0.076	0.072	0.006	0.000	0.003	-0.078

The 1999, 2000, and 2004 assessments show the greatest changes (in absolute magnitude), ranging in value between 7% and 8%. The 2004 assessment is the first assessment since 1998 to show a negative relative change.

Figure 2.9 plots the trajectory of fishing mortality and female spawning biomass from 1978 through 2004, overlaid with the current harvest control rules (biomass estimates from the EBS assessment model have been inflated to cover the entire BSAI stock–see "Survey Data" subsection of "Data" section). The entire trajectory lies underneath both harvest control rule except for the years 1978 and 1979. It should be noted that the current harvest control rules did not go into effect until 1999. In other words, fishing mortality rates have been well within the current limits throughout the period in which those limits have been in effect

Recruitment

Numbers at Age 3

Traditionally, recruitment strengths for Pacific cod have been assessed at age 3, because this is the approximate age of first significant recruitment to the fishery and because model estimates of relative year class strength tend to stabilize by this age. The model's estimated time series of age 3 recruitments is shown in Table 2.25, together with the estimates provided in last year's final SAFE report (Thompson and Dorn 2003). The model's recruitment estimates are also plotted in Figure 2.10. The current time series has a mean value of 277 million fish, a coefficient of variation of 57%, and an autocorrelation coefficient of 0.048.

One possible means of assigning a qualitative ranking to each year class within this time series is as follows: an "above average" year class can be defined as one in which numbers at age 3 are at least 120% of the mean, an "average" year class can be defined as one in which numbers at age 3 are less than 120% of the mean but at least 80% of the mean, and a "below average" year class can be defined as one in which numbers at age 3 are less than 80% of the mean. These criteria give the following classification of year class strengths:

Above average:	1976	1977	1979	1981	1982	1984	1989	1999			
Average:	1978	1983	1988	1991	1992	1995	1996	2000			
Below average:	1975	1980	1985	1986	1987	1990	1993	1994	1997	1998	2001

Of the 26 year classes estimated at age 3 in last year's assessment (Thompson and Dorn 2003), 14 (54%) have different rankings in the present assessment, due largely to the shift in the mean size at age estimated in the present assessment. The 1978, 1992, and 2000 year classes have been downgraded from "above average" to "average," the 1980, 1985, and 1990 year classes have been downgraded from "average" to "below average," the 1989 and 1999 year classes have been upgraded from "average" to "above average," the 1983, 1988, 1991, and 1995 year classes have been upgraded from "below average" to "average," and the 1976 and 1981 year classes have been upgraded all the way from "below average" to "above average." In addition, the 2001 year class has been added to the time series as a "below average" year class.

Numbers at Age 1

The model's estimated time series of age 1 recruitments is shown in Table 2.19. This time series has a mean value of 546 million fish, a coefficient of variation of 47%, and an autocorrelation coefficient of 0.14. The qualitative rankings of year class strengths at age 1 largely parallel the rankings at age 3, except that estimates for the 1975 and 1976 year classes do not exist at age 1 and the 2002 and 2003 year classes are added to the time series. The 2002 and 2003 year classes are presently estimated to be below average. However, it should be emphasized that the estimates of these year classes are based almost entirely on their appearance at ages 1 and 2 or age 1 in the two most recent surveys.

The present assessment model is not configured to estimate a stock-recruitment relationship. Estimation of stock-recruitment relationships is a notoriously difficult exercise in the field of stock assessment, because both the stock data and the recruitment data are measured with error and because the errors in the stock-recruitment data are autocorrelated (Walters and Ludwig 1981). Also, if the stock and recruitment data are generated by a model which assumes that no stock-recruitment relationship exists, these data will be biased. Nevertheless, the stock-recruitment relationship is potentially such an important component of stock dynamics that it seems prudent to provide some kind of investigation, albeit provisional, as to its possible shape. In addition, the SSC has requested that the assessment include a stock-recruitment relationship (SSC minutes, December, 2000; December, 2001; and December, 2002), and more recently has requested that stock-recruitment relationships be estimated separately for different portions of the time series (SSC minutes, December, 2003).

Based on evidence of a possible environmental regime shift in 1989 (Hare and Mantua 2000) and following the example of the 2003 BSAI rock sole assessment (Wilderbuer and Walters 2003), the age 1 recruitment time series was split into two portions, the first of which consisted of year classes spawned during the period 1977-1988 and the second of which consisted of year classes spawned during the period 1989-2002. Then, for each portion of the time series and for the overall time series, the following analysis was conducted (use of symbols in this description does not necessarily follow Table 2.13, which pertains to the Synthesis assessment model only):

1) Age 1 recruitment *R* in year *y*+1 was assumed to be related to spawning biomass *S* in year *y* by the Ricker (1954) stock-recruitment relationship subject to lognormal error:

$$R_{y+1} = S_y \exp\left(-\alpha - \beta S_y + \varepsilon_y\right),$$

where α and β are parameters and the ε_y are drawn from a normal distribution with mean 0 and variance σ^2.
2) The estimates of spawning biomass generated by Synthesis were treated as known constants (i.e., it was assumed that they are measured without error).
3) Parameters were estimated by the method of maximum likelihood.
4) The covariance of the parameter estimates was assumed to equal the inverse of the Hessian matrix.

The following parameter estimates resulted (ρ is the correlation between the estimates of α and β):

Parameter	Pre-1989	Post-1988	All years
α	-2.43	-0.808	-1.80
β	0.00477	0.00148	0.00379
σ	0.553	0.337	0.552
ρ	-0.863	-0.951	-0.906

Approximate 95% confidence ellipses for the estimated parameters of the three stock-recruitment relationships are shown in the upper panel of Figure 2.11 (these are "approximate" because maximum likelihood estimates are only asymptotically normal and the data sets considered here are fairly small). The fitted relationships are shown together with the data in the lower panel of Figure 2.11.

This analysis is useful mostly because it indicates a considerable level of uncertainty regarding the shape of the stock-recruitment relationship, manifested in the following ways: 1) As indicated by the correlation coefficients in the last row of the text table above and the shapes of the ellipses in the upper panel of Figure 2.11, the parameter estimates for each of the three curves are highly correlated. 2) The two portions of the time series seem to provide distinctly different pictures of the stock-recruitment relationship, as their approximate 95% confidence ellipses do not intersect (dotted and dashed ellipses in the upper panel of Figure 2.11). 3) While the amount of uncertainty evidenced in this analysis is high, the true statistical uncertainty is likely greater because of the problems noted in the description of the method above. Therefore, the estimates given here are not recommended for use in estimating MSY.

Exploitation

The model's estimated time series of the ratio between EBS catch and age 3+ biomass is shown in Table 2.26, together with the estimates provided in last year's final SAFE report (Thompson and Dorn 2003). The average value of this ratio over the entire time series is about 0.10. The estimated values exceed the average for every year after 1990 except 1993, whereas none of the estimated values exceed the average in any year prior to 1991.

PROJECTIONS AND HARVEST ALTERNATIVES

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, Pacific cod in the BSAI are managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. The following formulae apply under Tier 3:

3a) *Stock status:* $B/B_{40\%} > 1$
$F_{OFL} = F_{35\%}$
$F_{ABC} \leq F_{40\%}$
3b) *Stock status:* $1/20 < B/B_{40\%} \leq 1$
$F_{OFL} = F_{35\%} \times (B/B_{40\%} - 1/20) \times 20/19$
$F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - 1/20) \times 20/19$
3c) *Stock status:* $B/B_{40\%} \leq 1/20$
$F_{OFL} = 0$
$F_{ABC} = 0$

Estimation of the $B_{40\%}$ reference point used in the above formulae requires an assumption regarding the equilibrium level of recruitment. In this assessment, it is assumed that the equilibrium level of recruitment is equal to the post-1976 average (i.e., the arithmetic mean of all estimated recruitments from year classes spawned in 1977 or later). Other useful biomass reference points which can be calculated using this assumption are $B_{100\%}$ and $B_{35\%}$, defined analogously to $B_{40\%}$. These reference points are estimated as follows:

Reference point:	$B_{35\%}$	$B_{40\%}$	$B_{100\%}$
EBS:	226,000 t	258,000 t	646,000 t
BSAI:	266,000 t	304,000 t	760,000 t

For a stock exploited by multiple gear types, estimation of $F_{35\%}$ and $F_{40\%}$ requires an assumption regarding the apportionment of fishing mortality among those gear types. The current allocation formula (see "Fishery" section) was integrated into calculation of reference points in this assessment as follows: First, to simplify the analysis, it was assumed that the 1.4% of the fixed-gear allocation that is reserved for catcher vessels less than 60 ft. LOA would be taken in the longline fishery. Second, since available data are insufficient to estimate selectivities for the jig fishery, the jig fishery was merged into the other commercial fisheries. Third, total fishing mortality was apportioned between gear types (early trawl, late trawl, longline, and pot) at a ratio of 492:118:314:76. These proportions result in a 2005 catch composition that matches both the 47:51 trawl:fixed allocation, the 817:183 longline:pot allocation and the recent (2001-2003) average distribution of catches between the early and late trawl fisheries. It should be noted that this apportionment scheme is generally consistent with existing Steller sea lion (*Eumetopias jubatus*) protection measures. This apportionment results in the following estimates of $F_{35\%}$ and $F_{40\%}$:

$F_{35\%}$	$F_{40\%}$
0.43	0.36

Specification of OFL and Maximum Permissible ABC

BSAI spawning biomass for 2005 is estimated at a value of 295,000 t (EBS value = 251,000 t). This is about 3% below the BSAI $B_{40\%}$ value of 304,000 t (EBS value = 258,000 t), thereby placing Pacific cod in sub-tier "b" of Tier 3. Given this, the model estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2005 as follows:

	Overfishing Level	Maximum Permissible ABC
EBS catch:	225,000 t	193,000 t
BSAI catch:	265,000 t	227,000 t
Fishing mortality rate:	0.42	0.35

The age 3+ biomass estimates for 2005 are 1,290,000 t and 1,110,000 t for the BSAI and EBS, respectively.

ABC Recommendation

Review of Past Approaches

BSAI Pacific cod ABCs for the years 1998-2002 were based on a harvest strategy that attempted to address some of the statistical uncertainty in the assessment model, namely the uncertainty surrounding parameters the natural mortality rate M and survey catchability Q (Thompson and Dorn 1997, 1998, 1999). For the 2001-2002 ABCs, the strategy was simplified by assuming that the ratio between the recommended F_{ABC} and $F_{40\%}$ estimate given in the 1999 assessment (0.87) was an appropriate factor by which to multiply the current maximum permissible F_{ABC} to obtain a recommended F_{ABC} (Thompson and Dorn 2001). For the 2003 and 2004 ABCs, concerns regarding the performance of the assessment model led to a decision that kept ABC constant at the 2002 level of 223,000 t, well below the maximum permissible level estimated in the respective assessments (Thompson and Dorn 2002, 2003). However, it was emphasized in last year's assessment that the authors' recommendation to keep the 2004 ABC at the 2002-2003 level pertained to that assessment only, and should not be considered as an endorsement of the "constant catch" approach as a long-term management strategy (Thompson and Dorn 2003). Now that age and slope survey data have been added to the assessment model, the 2002-2004 ABC of 223,000 t is very near the maximum permissible level (227,000 t), and it may be appropriate to consider an alternative approach for recommending the 2005 ABC.

An Alternative Approach

The motivation for the adjustment factor used to set the 1998-2002 ABCs was twofold: 1) to provide a method of adjusting the ABC recommendation to account for uncertainty and 2) to base this method on a formal definition of risk aversion. While the method used to arrive at the 87% adjustment factor was consistent with these objectives, it was admittedly only an approximation constrained by the assessment model's ability to provide more explicit estimates of statistical uncertainty. The version of the Synthesis software used in the last several assessments and the current assessment is not designed to provide formal estimates of all the types of statistical uncertainty that would ideally be used in a full decision-theoretic approach. These types include uncertainty in future recruitment, uncertainty in annual estimates of numbers at age, and uncertainty in parameter estimates.

An alternative to the 87% adjustment factor, which would also be just an approximation, might focus on tradeoffs between alternative trajectories of expected catches produced by the standard projection model (see "Standard Harvest and Recruitment Scenarios and Projection Methodology" below). Using the current catch and current vector of estimated numbers at age as starting points, the standard projection model produces a trajectory of expected catches extending 13 years into the future (the minimum number of years needed to produce determinations of stock status under the National Standard Guidelines). Discussions regarding ABC often focus on comparisons between the expected catch trajectories under alternative harvest strategies. Two highly simplified examples are presented below, in each of which only two harvest strategies (F1 and F2) are considered and in each of which the projections extend only two years (rather than 13 years) into the future:

Example #1: A pair of hypothetical catch trajectories is shown below (year 0 is the current year):

Year:	0	1	2
Expected catch under F1:	200	170	140
Expected catch under F2:	200	230	260

Here, the expected catch in both trajectories changes by 30 units in years 1 and 2, the variance in both trajectories is 600, but the first trajectory has a mean of 170 and the second has a mean of 230. If everything else (e.g., impacts on the stock's ability to sustain the prescribed catches, impacts on other species in the ecosystem, etc.) were similar, the expected catch trajectory corresponding to F2 would probably be preferred.

Example #2: A different pair of hypothetical catch trajectories is shown below:

Year:	0	1	2
Expected catch under F1:	200	170	140
Expected catch under F2:	200	140	170

Here, the trajectory for F2 consists of the same set of numbers as the trajectory for F1, but in a different order. Both trajectories have a mean of 170 and a variance of 600. However, in the first trajectory, expected catch decreases by 30 units in years 1 and 2, whereas in the second trajectory, expected catch decreases by 60 units in year 1 then increases by 30 units in year 2. Although expected catch in year 2 changes by the same amount (30 units) under both harvest strategies, the year 1 change expected under harvest strategy F1 (30 units) is half that expected under F2 (60 units). In this sense, overall year-to-year variability is less under F1 than under F2. For Example #2, then, the expected catch trajectory corresponding to F1 would probably be preferred.

Summarizing the above pair of examples, harvest strategy F2 was preferred over F1 in Example #1 because average yield was higher while variability was equal, whereas in Example #2, harvest strategy F1 was preferred over F2 because variability (in some sense) was lower while average yield was equal. However, if a third example were imagined in which both average yield and variability were higher under one harvest strategy than the other, the preferred strategy might be less obvious. In such circumstances, choosing a preferred strategy would be facilitated if two questions were answered: 1) What is an appropriate definition of variability in this context? 2) What is an appropriate tradeoff between average yield and variability?

Possible answers to these questions can be obtained by considering the "uncertainty adjustment" used in Alternative 3b of the Programmatic Supplemental Environmental Impact Statement for the Alaska Groundfish Fisheries (NMFS 2004). Like the 87% adjustment factor used in previous Pacific cod assessments, Alternative 3b provided a method of adjusting the ABC recommendation to account for uncertainty based on a formal definition of risk aversion. Using Alternative 3b as a starting point, possible answers to the two questions in the above paragraph can be suggested as follows:

1) The theory underlying the Alternative 3b uncertainty adjustment focused on the long-term ("stationary") yield distribution. In that context, the variance of the long-term yield distribution arose as the appropriate measure of variability. However, the Pacific cod assessment currently lacks a satisfactory estimate of the stock-recruitment relationship, so estimating the variance of the long-term yield distribution is problematic. If the focus is instead shifted to the distribution of yields over the short term, then the "average squared first difference" (ASFD) would be a natural analogue. For the two examples described above, ASFD is computed as

$$[(\text{catch in year 1 - catch in year 0})^2 + (\text{catch in year 2 - catch in year 1})^2]/2$$

In Example #1, the ASFDs for the two harvest strategies are equal, as shown below:

Harvest Strategy	Average Squared First Difference
F1	$[(170\text{-}200)^2 + (140\text{-}170)^2]/2 = 900$
F2	$[(230\text{-}200)^2 + (260\text{-}230)^2]/2 = 900$

In Example #2, on the other hand, the ASFD for harvest strategy F1 is much lower than for harvest strategy F2, as shown below:

Harvest Strategy	Average Squared First Difference
F1	$[(170\text{-}200)^2 + (140\text{-}170)^2]/2 = 900$
F2	$[(140\text{-}200)^2 + (170\text{-}140)^2]/2 = 2250$

2) A special case of the Alternative 3b approach arises when yield is normally distributed. In this special case, the Alternative 3b objective would be to choose the harvest rate that maximizes the difference between average yield and half the variability. Although there is no reason to believe that the distribution of short-term future yields is exactly normal in the Pacific cod assessment, the normal distribution may be a reasonable first approximation.

Thus, an alternative approach for estimating ABC would be to find the harvest strategy that maximizes the difference between average yield and half the ASFD over the time frame covered by the standard projection model (13 years).

Recommendation for 2005

As shown in Figure 2.12, the objective function described above is maximized when the ABC fishing mortality rate is set at 90% of the maximum permissible ABC fishing mortality rate. A 90% adjustment factor results in a 2005 F_{ABC} of 0.31 and a 2005 ABC of 206,000 t. This ABC is about 8% below the 2002-2004 ABCs, about 4% below the projected year-end 2004 catch of 215,500 t (Mary Furuness, pers. commun., NMFS Alaska Region, Sustainable Fisheries Division), and about 5% above what the maximum permissible ABC would be if the Kalman filter estimates described in Attachment 2A were used under Tier 5. Because it is based on a method that views the tradeoff between average yield and variability in a systematic and reasonable fashion and because it is tied to a formal definition of risk aversion, a catch of 206,000 t is the recommended ABC for 2005.

In considering this recommendation, it should be understood that the methodology upon which it is based involves a substantial simplification of the full decision-theoretic approach and should therefore be viewed as a tool to be used temporarily until such time as a fuller quantification of the statistical uncertainty associated with the assessment becomes available.

Area Allocation of Harvests

At present, ABC of BSAI Pacific cod is not allocated by area. Pacific cod is something of an exception in this regard. Based on the Kalman filter approach described in Attachment 2A, the best estimate of the BSAI Pacific cod biomass distribution shows 85% residing in the EBS and 15% residing in the Aleutians. If a 2005 ABC of 206,000 t were apportioned accordingly, the EBS and AI portions would be 176,000 t and 30,000 t, respectively (rounded to the nearest thousand t). An alternative approach would be to use the Kalman filter estimate of current AI biomass to set a Tier 5 ABC for the AI, but it turns out that this approach also gives a 2005 value of 30,000 t (rounded to the nearest thousand t). An AI ABC of 30,000 t would be about 8% lower than the 2003 AI catch of 32,455 t. Thus, if there were no other management complications, setting a separate ABC for the AI would be expected to impose only a modest new constraint on the existing fishery while helping to control future expansion of the fishery in this area. However, at present, there are potentially significant management complications arising from certain allocation formulas (by gear type, CDQ, etc.) pertaining to Pacific cod in the Fishery Management Plan. Until such time as these complications can be resolved, specification of separate ABCs for the EBS and AI is not recommended.

Standard Harvest and Recruitment Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2004 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2005 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2004. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2005, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2005 recommended in the assessment to the *max* F_{ABC} for 2005. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of *max* F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1999-2003 average F, which was 0.23. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2005 or 2) above ½ of its MSY level in 2005 and above its MSY level in 2017 under this scenario, then the stock is not overfished.)

Scenario 7: In 2005 and 2006, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2017 under this scenario, then the stock is not approaching an overfished condition.)

Projections and Status Determination

Table 2.27 defines symbols used to describe projections of spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios. These projections are shown for Model 2 in Tables 2.28-34. For purposes of comparison, the projections are also shown for Model 1 in Attachment 2B (using a "constant catch" approach for scenario #2).

Harvest scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest scenarios #6 and #7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2005:

a) If spawning biomass for 2005 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b) If spawning biomass for 2005 is estimated to be above $B_{35\%}$, the stock is above its MSST.
c) If spawning biomass for 2005 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario #6 (Table 2.33). If the mean spawning biomass for 2015 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest scenario #7 (Table 2.34):

a) If the mean spawning biomass for 2007 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b) If the mean spawning biomass for 2007 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2007 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2017. If the mean spawning biomass for 2017 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

In the case of BSAI Pacific cod, spawning biomass for 2005 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Mean spawning biomass for 2007 in Table 2.34 is above $B_{35\%}$. Therefore, the stock is not approaching an overfished condition.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the Stock

A primary ecosystem phenomenon affecting the Pacific cod stock seems to be the occurrence of periodic "regime shifts," in which central tendencies of key variables in the physical environment change on a scale spanning several years to a few decades (Livingston, ed., 2002). One well-documented example of such a regime shift occurred in 1977, and shifts occurring in 1989 and 1999 have also been suggested (e.g., Hare and Mantua 2000). One of the principal indices used to measure the state of the environmental regime is the Pacific Decadal Oscillation ("PDO," Mantua et al. 1997). The time series of age 1 recruits (listed by cohort year) is presented along with monthly PDO values in Table 2.35. The recruitment time series does not show a very strong correlation with any of the monthly PDO time series, with values ranging from -0.25 to -0.06. All 12 monthly correlations are negative. It is possible that stronger correlations would be found if the recruitment time series extended prior to 1977.

The prey and predators of Pacific cod have been described or reviewed by Albers and Anderson (1985), Livingston (1989, 1991), and Westrheim (1996). In terms of percent occurrence, the most important items in the diet of Pacific cod in the BSAI and GOA are polychaetes, amphipods, and crangonid shrimp. In terms of numbers of individual organisms consumed, the most important dietary items are euphausids, miscellaneous fishes, and amphipods. In terms of weight of organisms consumed, the most important dietary items are walleye pollock, fishery offal, and yellowfin sole. Small Pacific cod feed mostly on invertebrates, while large Pacific cod are mainly piscivorous. Predators of Pacific cod include halibut, salmon shark, northern fur seals, Steller sea lions, harbor porpoises, various whale species, and tufted puffin. Major trends in the most important prey or predator species could be expected to affect the dynamics of Pacific cod to some extent.

Fishery Effects on the Ecosystem

Potentially, fisheries for Pacific cod can have effects on other species in the ecosystem through a variety of mechanisms, for example by relieving predation pressure on shared prey species (i.e., species which serve as prey for both Pacific cod and other species), by reducing prey availability for predators of Pacific cod, by altering habitat, by imposing bycatch mortality, or by "ghost fishing" caused by lost fishing gear.

<u>Bycatch of Nontarget and "Other" Species</u>

The methods described by Gaichas (2002) were used to estimate the bycatch imposed by the BSAI Pacific cod fisheries on various nontarget species and members of the "other species" group.

Tables 2.36a-f show these estimates in terms of both absolute bycatch amounts (metric tons or number of individuals, depending on the species group) and proportions of the total bycatch for each species group. Tables 2.36a-c show estimates for the EBS trawl, longline, and pot fisheries, respectively and Tables 2.36d-f show estimates for the AI trawl, longline, and pot fisheries, respectively.

It is not clear how much bycatch of a particular species constitutes "too much" in the context of ecosystem concerns. As a first step toward possible prioritization of future investigation into this question, it might be reasonable to focus on those species groups for which a Pacific cod fishery had a bycatch in excess of 100 t and accounted for more than 10% of the total bycatch in at least half of the six most recent years. This criterion results in the following list of impacted species groups (an "x" indicates that the criterion was met for that area/species/gear combination).

Area	Species group	Trawl	Longline	Pot
EBS	sculpins	x	x	
EBS	skates		x	
EBS	sleeper shark		x	
EBS	octopus			x
EBS	"other fish"	x		
EBS	anemones		x	
AI	sculpins	x	x	
AI	skates		x	

Steller Sea Lions

Sinclair and Zeppelin (2002) showed that Pacific cod was one of the four most important prey items of Steller sea lions in terms of frequency of occurrence averaged over years, seasons, and sites, and was especially important in winter. Pitcher (1981) and Calkins (1998) also showed Pacific cod to be an important winter prey item in the GOA and BSAI, respectively. Furthermore, the size ranges of Pacific cod harvested by the fisheries and consumed by Steller sea lions overlap, and the fishery operates to some extent in the same geographic areas used by Steller sea lion as foraging grounds (Livingston, ed., 2002).

The Fisheries Interaction Team of the Alaska Fisheries Science Center has been engaged in research to determine the effectiveness of recent management measures designed to mitigate the impacts of the Pacific cod fisheries (among others) on Steller sea lions. Results from studies conducted in 2002-2003 were summarized by Conners et al. (2004). These studies included a tagging feasibility study, which may evolve into an ongoing research effort capable of providing information on the extent and rate to which Pacific cod move in and out of various portions of Steller sea lion critical habitat. Nearly 6,000 spaghetti tags were released, of which approximately 1,000 had been returned as of September, 2003. Return data are still being analyzed, but a preliminary plot shows that many fish were recaptured in the same general area as they were released.

Seabirds

The following is a summary of information provided by Livingston (ed., 2002): In both the BSAI and GOA, the northern fulmar (*Fulmarus glacialis*) comprises the majority of seabird bycatch, which occurs primarily in the longline fisheries, including the longline fishery for Pacific cod (Tables 2.36b and 2.36e). Shearwater (*Puffinus* spp.) distribution overlaps with the Pacific cod longline fishery in the Bering Sea, and with trawl fisheries in general in both the Bering Sea and GOA. Black-footed albatross (*Phoebastria nigripes*) is taken in much greater numbers in the GOA longline fisheries than the Bering Sea longline fisheries, but is not taken in the trawl fisheries. The distribution of Laysan albatross (*Phoebastria immutabilis*) appears to overlap with the longline fisheries in the central and western Aleutians. The distribution of short-tailed albatross (*Phoebastria albatrus*) also overlaps with the Pacific cod longline fishery along the Aleutian chain, although the majority of the bycatch has taken place along the northern portion of the Bering Sea shelf edge (in contrast, only two takes have been recorded in the

GOA). Some success has been obtained in devising measures to mitigate fishery-seabird interactions. For example, on vessels larger than 60 ft. LOA, paired streamer lines of specified performance and material standards have been found to reduce seabird incidental take significantly.

Fishery Usage of Habitat

The following is a summary of information provided by Livingston (ed., 2002): The longline and trawl fisheries for Pacific cod each comprise an important component of the combined fisheries associated with the respective gear type in each of the three major management regions (BS, AI, and GOA). Looking at each gear type in each region as a whole (i.e., aggregating across all target species) during the period 1998-2001, the total number of observed sets was as follows:

Gear	BS	AI	GOA
Trawl	240,347	43,585	68,436
Longline	65,286	13,462	7,139

In the BS, both longline and trawl effort was concentrated north of False Pass (Unimak Island) and along the shelf edge represented by the boundary of areas 513, 517 (in addition, longline effort was concentrated along the shelf edge represented by the boundary of areas 521-533). In the AI, both longline and trawl effort was dispersed over a wide area along the shelf edge. The catcher vessel longline fishery in the AI occurred primarily over mud bottoms. Longline catcher-processors in the AI tended to fish more over rocky bottoms. In the GOA, fishing effort was also dispersed over a wide area along the shelf, though pockets of trawl effort were located near Chirikof, Cape Barnabus, Cape Chiniak and Marmot Flats. The GOA longline fishery for Pacific cod generally took place over gravel, cobble, mud, sand, and rocky bottoms, in depths of 25 fathoms to 140 fathoms.

Data Gaps and Research Priorities

Understanding of the above ecosystem considerations would be improved if future research were directed toward closing certain data gaps. Such research would have several foci, including the following: 1) ecology of the Pacific cod stock, including spatial dynamics, trophic and other interspecific relationships, and the relationship between climate and recruitment; 2) behavior of the Pacific cod fishery, including spatial dynamics; 3) determinants of trawl survey selectivity; 4) ecology of species taken as bycatch in the Pacific cod fisheries, including estimation of biomass, carrying capacity, and resilience; and 5) ecology of species that interact with Pacific cod, including estimation of biomass, carrying capacity, and resilience.

SUMMARY

The major results of the Pacific cod stock assessment are summarized in Table 2.37.

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REFERENCES

Albers, W. D., and P. J. Anderson. 1985. Diet of Pacific cod, *Gadus macrocephalus*, and predation on the northern pink shrimp, *Pandalus borealis*, in Pavlof Bay, Alaska. Fish. Bull., U.S. 83:601-610.

Bakkala, R. G., and V. G. Wespestad. 1985. Pacific cod. *In* R. G. Bakkala and L. L. Low (editors), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1984, p. 37-49. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-83.

Barbeaux, S., J. Ianelli, and E. Brown. This volume. Stock assessment of Aleutian Islands pollock.

Burnham, K. P., and D. R. Anderson. 1998. Model Selection and Inference: A Practical Information-Theoretic Approach. Springer-Verlag, New York. 353 p.

Calkins, D. G. 1998. Prey of Steller sea lions in the Bering Sea. Biosphere Conservation 1:33-44.

Conners, M. E., P. Munro, and S. Neidetcher. 2004. Pacific cod pot studies 2002-2003. Alaska Fisheries Science Center Proc. Rep. 2004-04. 64 p. plus appendices.

Fournier, D. A. 1983. An analysis of the Hecate Strait Pacific cod fishery using an age-structured model incorporating density-dependent effects. Can. J. Fish. Aquat. Sci. 40:1233-1243.

Fournier, D., and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 38:1195-1207.

Gaichas, S. 2002. Squid and other species in the Bering Sea and Aleutian Islands. *In* Plan Team for the Groundfish Fisheries of the Bering Sea and Aleutian Islands (compiler), Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, p. 670-699. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Grant, W. S., C. I. Zhang, and T. Kobayashi. 1987. Lack of genetic stock discretion in Pacific cod (*Gadus macrocephalus*). Can. J. Fish. Aquat. Sci. 44:490-498.

Hare, S. R., and N. J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography 47:103-146.

Ketchen, K.S. 1964. Preliminary results of studies on a growth and mortality of Pacific cod (*Gadus macrocephalus*) in Hecate Strait, British Columbia. J. Fish. Res. Bd. Canada 21:1051-1067.

Livingston, P. A. 1989. Interannual trends in Pacific cod, Gadus macrocephalus, predation on three commercially important crab species in the eastern Bering Sea. Fish. Bull., U.S. 87:807-827.

Livingston, P. A. 1991. Pacific cod. *In* P. A. Livingston (editor), Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1984 to 1986, p. 31-88. U.S. Dept. Commer., NOAA Tech. Memo. NMFS F/NWC-207.

Livingston, P. A. (editor). 2003. Ecosystem Considerations for 2003. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Low, L. L. 1974. A study of four major groundfish fisheries of the Bering Sea. Ph.D. Thesis, Univ. Washington, Seattle, WA 240 p.

McAllister, M. K., and J. N. Ianelli. 1997. Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. Can. J. Fish. Aquat. Sci. 54:284-300.

Methot, R. D. 1986. Synthetic estimates of historical abundance and mortality for northern anchovy, *Engraulis mordax*. NMFS, Southwest Fish. Cent., Admin. Rep. LJ 86-29, La Jolla, CA.
Methot, R. D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. Int. N. Pac. Fish. Comm. Bull. 50:259-277.
Methot, R. D. 1998. Application of stock synthesis to NRC test data sets. *In* V. R. Restrepo (editor), Analyses of simulated data sets in support of the NRC study on stock assessment methods, p. 59-80. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-30.
Methot, R. D. 2000. Technical description of the stock synthesis assessment program. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-43, 46 p.
Pitcher, K. W. 1981. Prey of Steller sea lion, *Eumetopias jubatus*, in the Gulf of Alaska. Fishery Bulletin 79:467-472.
Prentice, R. L. 1976. A generalization of the probit and logit methods for dose response curves. Biometrics 32:761-768.
Ricker, W. E. 1954. Stock and recruitment. J. Fish. Res. Board Can. 11:559-63.
Roberson, N. E. 2001. Age determination of Pacific cod (*Gadus macrocephalus*). MS thesis, University of Washington, Seattle, WA. 44 p.
Shimada, A. M., and D. K. Kimura. 1994. Seasonal movements of Pacific cod (*Gadus macrocephalus*) in the eastern Bering Sea and adjacent waters based on tag-recapture data. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 92:800-816.
Sinclair, E.S. and T. K. Zeppelin. 2002. Seasonal and spatial differences in diet in the western stock of Steller sea lions (*Eumetopias jubatus*). Journal of Mammalogy 83(4).
Somerton, D. A. 2004. Do Pacific cod (*Gadus macrocephalus*) and walleye pollock *(Theregra chalcogramma*) lack a herding response to the doors, bridles, and mudclouds of survey trawls? ICES Journal of Marine Science 61:1186-1189.
Thompson, G. G., and M. W. Dorn. 1997. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 121-158. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.
Thompson, G. G., and M. W. Dorn. 1998. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 113-181. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.
Thompson, G. G., and M. W. Dorn. 1999. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 151-230. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.
Thompson, G. G., and M. K. Dorn. 2001. Assessment of the Pacific cod stock in the eastern Bering Sea and Aleutian Islands area. *In* Plan Team for the Groundfish Fisheries of the Bering Sea and Aleutian Islands (compiler), Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, p. 2.1-2.74. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.
Thompson, G. G., and M. K. Dorn. 2002. Assessment of the Pacific cod stock in the eastern Bering Sea and Aleutian Islands area. *In* Plan Team for the Groundfish Fisheries of the Bering Sea and Aleutian Islands (compiler), Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, p. 121-205. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.
Thompson, G. G., and M. W. Dorn. 2003. Assessment of the Pacific cod stock in the Eastern Bering Sea and Aleutian Islands Area. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 127-222. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.
Thompson, G. G., and R. D. Methot. 1993. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands region as projected for 1994, chapter 2.

North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., and A. M. Shimada. 1990. Pacific cod. *In* L. L. Low and R. E. Narita (editors), Condition of groundfish resources of the eastern Bering Sea-Aleutian Islands region as assessed in 1988, p. 44-66. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Thompson, G. G, and H. H. Zenger. 1993. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 1994, chapter 2. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., and H. H. Zenger. 1995. Pacific cod. *In* Plan Team for the Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 1996, chapter 2. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., H. H. Zenger, and M. W. Dorn. 1997. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 121-163. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., H. H. Zenger, and M. W. Dorn. 1998. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 91-155. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., H. H. Zenger, and M. W. Dorn. 1999. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 105-184. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Walters, C. J., and D. Ludwig. 1981. Effects of measurement errors on the assessment of stock-recruitment relationships. Can. J. Fish. Aquat. Sci. 38:704-710.

Wespestad, V., R. Bakkala, and J. June. 1982. Current abundance of Pacific cod (*Gadus macrocephalus*) in the eastern Bering Sea and expected abundance in 1982-1986. NOAA Tech. Memo. NMFS F/NWC-25, 26 p.

Westrheim, S. J. 1996. On the Pacific cod (*Gadus macrocephalus*) in British Columbia waters, and a comparison with Pacific cod elsewhere, and Atlantic cod (*G. morhua*). Can. Tech. Rep. Fish. Aquat. Sci. 2092. 390 p.

Wilderbuer, T. K. and T. M. Sample. 2003. Arrowtooth flounder. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 367-408. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Wilderbuer, T. K. and G. E. Walters. 2003. Rock sole. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 409-462. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Table 2.1a--Summary of catches (t) of Pacific cod by management area, fleet sector, and gear type. All catches since 1980 include discards. LLine = longline, Subt. = sector subtotal. Catches for 2004 are through mid-October. Catches by gear are not available prior to 1981.

Eastern Bering Sea Only:

Year	Foreign			Joint Venture		Domestic Annual Processing					Total
	Trawl	LLine	Subt.	Trawl	Subt.	Trawl	LLine	Pot	Other	Subt.	
1978			42512		0					31	42543
1979			32981		0					780	33761
1980			35058		8370					2433	45861
1981	30347	5851	36198	7410	7410	12884	1	0	14	12899	56507
1982	23037	3142	26179	9312	9312	23893	5	0	1715	25613	61104
1983	32790	6445	39235	9662	9662	45310	4	21	569	45904	94801
1984	30592	26642	57234	24382	24382	43274	8	0	205	43487	125103
1985	19596	36742	56338	35634	35634	51425	50	0	0	51475	143447
1986	13292	26563	39855	57827	57827	37646	48	62	167	37923	135605
1987	7718	47028	54746	47722	47722	46039	1395	1	0	47435	149903
1988	0	0	0	106592	106592	93706	2474	299	0	96479	203071
1989	0	0	0	44612	44612	119631	13935	145	0	133711	178323
1990	0	0	0	8078	8078	115493	47114	1382	0	163989	172067
1991	0	0	0	0	0	129392	76734	3343	0	209469	209469
1992	0	0	0	0	0	77259	80174	7512	33	164978	164978
1993	0	0	0	0	0	81790	49295	2098	2	133185	133185
1994	0	0	0	0	0	84931	78566	8037	730	172264	172264
1995	0	0	0	0	0	110956	97665	19275	599	228496	228496
1996	0	0	0	0	0	91910	88882	28006	267	209064	209064
1997	0	0	0	0	0	93924	117008	21493	173	232598	232598
1998	0	0	0	0	0	60780	84323	13232	192	158526	158526
1999	0	0	0	0	0	51902	81463	12399	100	145865	145865
2000	0	0	0	0	0	53815	81640	15849	68	151372	151372
2001	0	0	0	0	0	35655	90360	16385	52	142452	142452
2002	0	0	0	0	0	51065	100269	15051	166	166552	166552
2003	0	0	0	0	0	47580	106967	21957	155	176659	176659
2004	0	0	0	0	0	55166	74681	14986	214	145047	145047

Table 2.1b--Summary of catches (t) of Pacific cod by management area, fleet sector, and gear type. All catches since 1980 include discards. LLine = longline, Subt. = sector subtotal. Catches for 2004 are through mid-October. Catches by gear are not available prior to 1981.

Aleutian Islands Region Only:

Year	Foreign			Joint Venture		Domestic Annual Processing					Total
	Trawl	LLine	Subt.	Trawl	Subt.	Trawl	LLine	Pot	Other	Subt.	
1978			0		0					0	0
1979			0		0					0	0
1980			0		86					0	86
1981	2680	235	2915	1749	1749	2744	26	0	0	2770	7434
1982	1520	476	1996	4280	4280	2121	0	0	0	2121	8397
1983	1869	402	2271	4700	4700	1459	0	0	0	1459	8430
1984	473	804	1277	6390	6390	314	0	0	0	314	7981
1985	10	829	839	5638	5638	460	0	0	0	460	6937
1986	5	0	5	6115	6115	784	1	1	0	786	6906
1987	0	0	0	10435	10435	2662	22	88	0	2772	13207
1988	0	0	0	3300	3300	1698	137	30	0	1865	5165
1989	0	0	0	6	6	4233	284	19	0	4536	4542
1990	0	0	0	0	0	6932	602	7	0	7541	7541
1991	0	0	0	0	0	3414	3203	3180	0	9797	9797
1992	0	0	0	0	0	14558	22108	6317	84	43068	43068
1993	0	0	0	0	0	17312	16860	0	33	34204	34204
1994	0	0	0	0	0	14382	7009	147	0	21539	21539
1995	0	0	0	0	0	10574	4935	1024	0	16534	16534
1996	0	0	0	0	0	21179	5819	4611	0	31609	31609
1997	0	0	0	0	0	17349	7151	575	89	25164	25164
1998	0	0	0	0	0	20531	13771	424	0	34726	34726
1999	0	0	0	0	0	16437	7874	3750	69	28130	28130
2000	0	0	0	0	0	20362	16183	3107	33	39684	39684
2001	0	0	0	0	0	15826	17817	544	19	34207	34207
2002	0	0	0	0	0	27929	2865	7	0	30801	30801
2003	0	0	0	0	0	31478	974	2	0	32455	32455
2004	0	0	0	0	0	25090	2483	0	0	27573	27573

Table 2.1c--Summary of catches (t) of Pacific cod by management area, fleet sector, and gear type. All catches since 1980 include discards. LLine = longline, Subt. = sector subtotal. Catches for 2004 are through mid-October. Catches by gear are not available prior to 1981.

Eastern Bering Sea and Aleutian Islands Region Combined:

Year	Foreign			Joint Venture		Domestic Annual Processing					Total
	Trawl	LLine	Subt.	Trawl	Subt.	Trawl	LLine	Pot	Other	Subt.	
1978			42512		0					31	42543
1979			32981		0					780	33761
1980			35058		8456					2433	45947
1981	33027	6086	39113	9159	9159	15628	27	0	14	15669	63941
1982	24557	3618	28175	13592	13592	26014	5	0	1715	27734	69501
1983	34659	6847	41506	14362	14362	46769	4	21	569	47363	103231
1984	31065	27446	58511	30772	30772	43588	8	0	205	43801	133084
1985	19606	37571	57177	41272	41272	51885	50	0	0	51935	150384
1986	13297	26563	39860	63942	63942	38430	49	63	167	38709	142511
1987	7718	47028	54746	58157	58157	48701	1417	89	0	50207	163110
1988	0	0	0	109892	109892	95404	2611	329	0	98344	208236
1989	0	0	0	44618	44618	123864	14219	164	0	138247	182865
1990	0	0	0	8078	8078	122425	47716	1389	0	171530	179608
1991	0	0	0	0	0	132806	79937	6523	0	219266	219266
1992	0	0	0	0	0	91818	102282	13829	117	208046	208046
1993	0	0	0	0	0	99102	66155	2098	35	167389	167389
1994	0	0	0	0	0	99313	85575	8184	730	193802	193802
1995	0	0	0	0	0	121530	102600	20299	599	245029	245029
1996	0	0	0	0	0	113089	94701	32617	267	240673	240673
1997	0	0	0	0	0	111273	124159	22068	262	257762	257762
1998	0	0	0	0	0	81310	98094	13657	192	193253	193253
1999	0	0	0	0	0	68339	89337	16150	169	173995	173995
2000	0	0	0	0	0	74177	97823	18956	101	191056	191056
2001	0	0	0	0	0	51482	108177	16929	71	176659	176659
2002	0	0	0	0	0	78994	103134	15058	166	197352	197352
2003	0	0	0	0	0	79059	107941	21959	156	209114	209114
2004	0	0	0	0	0	80256	77164	14986	214	172620	172620

Table 2.2--History of Pacific cod ABC, TAC, total BSAI catch, and type of stock assessment model used to recommend ABC. Catch for 2004 is current through mid-October.

Year	ABC	TAC	Catch	Stock Assessment Model
1980	148,000	70,700	45,947	projection of 1979 survey numbers at age
1981	160,000	78,700	63,941	projection of 1979 survey numbers at age
1982	168,000	78,700	69,501	projection of 1979 survey numbers at age
1983	298,200	120,000	103,231	projection of 1979 survey numbers at age
1984	291,300	210,000	133,084	projection of 1979 survey numbers at age
1985	347,400	220,000	150,384	projection of 1979-1985 survey numbers at age
1986	249,300	229,000	142,511	separable age-structured model
1987	400,000	280,000	163,110	separable age-structured model
1988	385,300	200,000	208,236	separable age-structured model
1989	370,600	230,681	182,865	separable age-structured model
1990	417,000	227,000	179,608	separable age-structured model
1991	229,000	229,000	219,266	separable age-structured model
1992	182,000	182,000	208,046	age-structured Synthesis model
1993	164,500	164,500	167,389	length-structured Synthesis model
1994	191,000	191,000	193,802	length-structured Synthesis model
1995	328,000	250,000	245,029	length-structured Synthesis model
1996	305,000	270,000	240,673	length-structured Synthesis model
1997	306,000	270,000	257,762	length-structured Synthesis model
1998	210,000	210,000	193,253	length-structured Synthesis model
1999	177,000	177,000	173,995	length-structured Synthesis model
2000	193,000	193,000	191,056	length-structured Synthesis model
2001	188,000	188,000	176,659	length-structured Synthesis model
2002	223,000	200,000	197,352	length-structured Synthesis model
2003	223,000	207,500	209,114	length-structured Synthesis model
2004	223,000	215,500	172,620	length-structured Synthesis model

Table 2.3–Pacific cod discard rates by area, target species/group, and year. The discard rate is the ratio of discarded Pacific cod catch to total Pacific cod catch for a given area/target/year combination. An empty cell indicates that no Pacific cod were caught in that area/target/year combination. Note that the absolute amount of discards may be small even if the discard rate is large.

Eastern Bering Sea

Target species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Arrowtooth flounder	0.61	0.00	0.94		0.66	0.08	0.07	1.00	1.00	0.99	1.00	0.22	0.01
Atka mackerel	1.00		0.70	1.00		0.23		0.51	0.00	0.00	1.00		0.02
Flathead sole					0.39	0.58	0.10	0.75	0.87	0.75	0.00	1.00	0.00
Greenland turbot	0.01	0.00	0.12	0.04	0.35	0.09	0.03	0.04	0.13	0.10	0.01	0.18	0.07
Other flatfish	0.63	0.31	0.47	0.88	0.22	0.28	0.91	0.28	0.33	0.32	0.00	0.00	
Other species	0.04	0.99	0.38		1.00	1.00	0.01	0.95	0.07	0.92	0.08	0.00	0.02
Pacific cod	0.03	0.04	0.08	0.06	0.07	0.04	0.03	0.02	0.01	0.02	0.01	0.02	0.01
Pollock	0.70	0.85	0.73	0.68	0.21	0.41	0.24	0.42	0.49	0.68	0.84	0.52	0.00
Rock sole	1.00	0.00	0.08	0.87	0.25	0.90		1.00	0.02	0.16	1.00	1.00	0.08
Rockfish	1.00	0.00	0.89	0.01	0.84	0.69	0.16		0.00	0.03	0.00	0.00	
Sablefish	0.00	0.12	0.42	0.40	0.96	0.94	0.78	0.93	0.61	0.98	0.12	0.48	0.43
Unknown	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.49	0.04	0.02			
Yellowfin sole		0.74	0.72	0.50	0.08	1.00	0.24	0.77	0.50	0.60	0.39	0.77	0.06
Grand Total	0.03	0.04	0.08	0.06	0.07	0.04	0.03	0.02	0.01	0.02	0.01	0.02	0.02

Aleutian Islands

Target species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Arrowtooth flounder	1.00										0.00	0.00	0.03
Atka mackerel								1.00		1.00	1.00	1.00	
Flathead sole		0.35											
Greenland turbot	0.11	0.00	0.73	0.58	0.40	0.89	0.04	0.01	0.18	0.40	0.00	0.00	
Other species		1.00			0.00				0.14	0.08	0.00	0.06	0.00
Pacific cod	0.02	0.03	0.12	0.09	0.04	0.04	0.05	0.02	0.02	0.02	0.01	0.02	0.01
Pollock	0.76	0.00	0.29	0.00	0.47	0.74	0.75	0.61	0.00				
Rock sole			0.00										0.11
Rockfish	0.83		0.75	0.28	0.18	0.80	0.91	1.00	0.64	0.12	0.22	0.03	0.00
Sablefish	1.00	0.04	0.49	0.52	0.97	0.53	0.70	0.88	0.51	0.31	0.06	0.76	0.37
Unknown	0.09				1.00	1.00		0.03		1.00	1.00		
Grand Total	0.04	0.03	0.12	0.09	0.12	0.04	0.06	0.02	0.02	0.02	0.01	0.02	0.01

Table 2.4–EBS catch (t) of Pacific cod by year, gear, and period. Catch for 2004 is complete through August. Catches taken by jig gear have been merged with other gear types. Distribution of pre-1981 catches by gear and period was estimated from other years' data.

Year	Trawl			Longline			Pot		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
1978	10424	11288	18021	1371	1032	1856	0	0	0
1979	10397	12587	10403	1371	699	547	0	0	0
1980	9452	9007	17039	1106	206	4230	0	0	0
1981	15067	14087	21486	1286	624	3942	0	0	0
1982	21742	18151	16348	363	475	2308	0	0	0
1983	40757	24300	22705	2941	748	2756	0	0	0
1984	48237	24964	25045	5012	2128	19508	0	0	0
1985	55673	28673	22310	13703	1710	21379	0	0	0
1986	59786	26598	22382	8895	438	17278	0	0	0
1987	64413	15604	21462	20947	723	26752	0	0	0
1988	127470	25662	47166	444	646	1385	90	51	160
1989	127459	16986	19798	3810	4968	5157	33	63	49
1990	101645	11402	10524	13171	16643	17299	0	986	395
1991	107979	15549	5863	25470	21472	29792	12	1042	2288
1992	59460	11840	5959	49696	24201	6276	2622	4632	258
1993	67148	5362	9280	49244	27	23	2073	24	0
1994	61009	5806	18115	57968	13	20585	4923	0	3113
1995	90366	8543	12047	68458	26	29180	12484	3469	3322
1996	78194	3126	10590	62011	26	26845	18143	6401	3462
1997	81313	3927	8684	70676	43	46290	14584	3576	3333
1998	45008	5603	10169	54234	18	30071	9022	2779	1432
1999	44904	3312	3686	55180	1923	24360	9346	1001	2052
2000	44508	4578	4730	40180	1375	40086	15742	0	107
2001	22849	7025	5781	38368	6700	45291	11645	442	4298
2002	37008	9554	4503	50024	12132	38113	10852	401	3799
2003	34515	9986	3079	53156	11032	42773	15452	74	6586
2004	41513	11315		56047	9482		12448	518	

Table 2.5--Pacific cod length sample sizes from the commercial fisheries. Data for 2004 are complete through mid-October.

Year	Trawl Fishery			Longline Fishery			Pot Fishery		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	646	0	3161	2885	4886	2514	0	0	0
1979	1667	0	748	11410	2514	2662	0	0	0
1980	1359	73	327	2600	1389	2932	0	0	0
1981	132	0	1540	2253	1276	1300	0	0	0
1982	592	226	1643	2910	1203	5078	0	0	0
1983	12386	1231	14577	18800	4119	9610	0	0	0
1984	10246	4482	4477	6853	6004	82103	0	0	0
1985	30171	1556	3051	0	4561	134469	0	0	0
1986	28566	1813	2548	18588	200	104142	0	0	0
1987	46360	6674	20923	70273	0	165124	0	0	0
1988	103453	0	2897	0	0	0	0	0	0
1989	58575	612	669	0	0	0	0	0	0
1990	64143	9807	250	18900	74534	62550	0	1506	5772
1991	88727	2083	0	54671	70808	91693	0	10701	11243
1992	79286	0	0	152152	134263	20129	17289	48569	5147
1993	81637	0	0	154337	0	0	10557	0	0
1994	103839	0	0	172585	0	45350	25950	0	6436
1995	68575	0	0	144739	392	74766	47660	16786	13741
1996	104295	1139	3473	164051	156	75385	76393	23063	11199
1997	106847	275	0	184741	109	144489	43859	11760	11760
1998	108187	2790	2974	162821	62	190555	26595	8899	4522
1999	44845	228	1136	84227	10095	51065	22634	1875	8922
2000	47085	304	67	71413	9960	97697	26040	0	512
2001	26124	2787	1304	84559	27431	102235	15985	447	8447
2002	38042	4583	2362	75151	31360	85824	11155	367	6250
2003	24486	8205	1975	94988	36965	102742	12251	0	7821
2004	19258	6592	556	78073	16163	700	8822	323	1097

Table 2.6–Length frequencies of Pacific cod in the pre-1989 trawl fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1978	1	0	0	0	1	1	1	1	2	5	22	29	88	233	112	44	32	36	15	11	9	1	1	2	0	0
1978	3	0	0	0	0	0	6	35	79	37	21	19	5	62	387	999	882	337	159	81	37	13	2	0	0	0
1979	1	0	0	0	0	0	2	1	21	46	94	206	319	346	100	149	161	152	48	11	4	5	1	1	0	0
1979	3	0	0	0	0	0	0	0	3	5	24	74	150	220	78	38	47	58	31	14	4	0	0	0	1	1
1980	1	0	0	0	0	0	0	1	10	34	84	186	295	462	192	49	19	14	8	3	1	1	0	0	0	0
1980	2	0	0	0	0	0	0	0	0	0	0	0	0	1	16	45	8	3	0	0	0	0	0	0	0	0
1980	3	0	0	0	0	0	0	0	1	0	0	9	17	37	79	70	55	32	8	9	6	3	0	1	0	0
1981	1	0	0	0	0	0	0	0	0	0	0	0	8	28	43	34	16	3	0	0	0	0	0	0	0	0
1981	3	0	0	0	0	0	0	0	2	1	0	3	8	26	122	336	373	301	194	120	32	13	7	2	0	0
1982	1	0	0	0	0	0	1	1	4	21	22	9	13	48	61	94	133	84	69	20	8	3	1	0	0	0
1982	2	0	0	0	0	0	0	0	0	0	1	1	7	21	14	21	41	43	33	16	13	4	6	4	1	0
1982	3	0	0	0	0	0	0	1	0	0	1	4	27	70	143	215	196	302	346	215	90	18	9	5	1	0
1983	1	0	0	0	0	0	5	20	99	286	284	275	467	1113	1272	1978	2477	1982	1193	584	202	72	35	22	13	7
1983	2	0	0	0	0	0	1	0	1	3	10	4	7	31	95	204	289	249	187	85	30	11	8	6	7	3
1983	3	0	0	0	0	1	15	24	26	15	8	35	205	421	508	1451	1999	2487	2441	2235	1563	767	284	66	21	5
1984	1	0	1	1	1	0	7	121	251	222	132	66	148	439	503	758	1394	2027	1873	1278	639	263	96	16	9	1
1984	2	0	1	0	0	5	18	14	5	10	55	93	118	241	284	403	612	638	620	481	411	313	110	42	7	1
1984	3	0	0	0	0	0	7	21	15	114	434	370	188	137	124	254	396	576	614	483	376	224	99	32	13	0
1985	1	0	0	2	0	4	0	2	39	116	262	733	1768	2246	1088	1415	2474	5067	5635	4340	2649	1402	608	229	69	23
1985	2	0	0	0	0	0	0	0	3	24	77	70	119	425	356	116	59	70	88	73	35	20	8	9	3	1
1985	3	0	0	0	0	0	0	0	1	0	9	79	170	533	322	195	126	288	424	374	296	152	78	4	0	0
1986	1	0	4	16	8	34	62	118	249	636	761	683	788	2229	3564	3293	2108	2647	3498	3377	2446	1346	456	168	58	17
1986	2	0	0	0	0	0	0	7	4	2	4	5	9	26	95	130	195	285	481	352	128	48	30	8	4	0
1986	3	0	0	1	0	0	0	2	1	15	17	28	26	86	169	288	405	520	406	265	136	93	59	22	4	5
1987	1	0	0	3	13	15	58	194	446	516	640	1250	2235	4300	3164	3663	6190	6238	5028	4338	3669	2326	1255	510	234	75
1987	2	0	0	0	0	1	1	2	5	9	6	10	29	135	241	422	837	1294	1344	889	574	397	252	133	68	25
1987	3	0	0	0	0	0	0	0	0	7	13	68	76	263	1095	1809	2177	2736	3204	2732	2087	1946	1549	802	306	53
1988	1	1	0	1	1	6	30	93	605	1533	2081	2311	4634	11994	11361	10890	9690	10862	13124	11333	6319	3330	1855	913	380	106
1988	3	0	0	0	0	0	0	0	0	5	0	13	52	257	326	284	348	348	373	332	305	166	56	20	6	6

Table 2.7–Length frequencies of Pacific cod in the pre-1989 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1978	1	0	0	0	0	0	0	0	0	1	4	23	124	623	812	435	269	216	160	110	58	36	7	7	0	0
1978	2	0	0	0	0	0	0	0	0	0	1	7	40	240	574	1226	994	716	566	330	133	44	12	2	1	0
1978	3	0	0	0	0	0	0	0	0	0	0	2	0	62	366	736	788	306	124	66	35	19	8	2	0	0
1979	1	0	0	0	0	0	0	0	8	83	377	683	436	375	1303	2454	2711	1575	679	380	208	87	36	8	7	0
1979	2	0	0	0	0	0	0	0	0	2	14	49	90	155	102	327	646	660	315	86	43	17	5	3	0	0
1979	3	0	0	0	0	0	0	0	0	0	2	10	47	233	249	174	387	683	599	216	41	10	9	2	0	0
1980	1	0	0	0	0	0	0	0	0	5	15	66	212	591	604	320	182	199	244	111	36	11	4	0	0	0
1980	2	0	0	0	0	0	0	0	0	0	0	1	29	169	334	293	185	148	140	67	17	4	2	0	0	0
1980	3	0	0	0	0	0	0	0	0	0	0	1	18	235	558	679	652	350	194	138	76	25	5	0	1	0
1981	1	0	0	0	0	5	18	7	7	10	0	18	48	285	503	453	340	198	153	89	70	36	9	4	0	0
1981	2	0	0	0	0	0	0	0	0	2	1	8	29	88	160	265	292	228	108	35	32	24	3	1	0	0
1981	3	0	0	0	0	0	0	0	0	0	0	0	2	8	86	230	318	300	220	89	29	15	2	0	1	0
1982	1	0	0	0	0	0	0	0	1	1	14	22	30	215	381	520	550	468	298	167	100	78	47	13	3	2
1982	2	0	0	0	0	0	0	0	0	0	9	43	17	102	208	164	211	164	133	80	48	11	7	3	3	0
1982	3	0	0	0	0	0	0	0	1	0	1	15	35	107	270	512	830	1195	1101	639	240	82	35	9	4	2
1983	1	0	0	0	0	0	0	0	1	3	21	51	178	1231	1673	2160	2944	3606	3254	2018	876	390	220	117	48	9
1983	2	0	0	0	0	0	0	0	0	1	4	18	24	118	414	454	580	676	704	520	368	154	55	19	10	0
1983	3	0	0	0	0	0	0	1	0	0	0	4	28	129	459	1163	1262	1550	1779	1565	993	477	148	37	9	6
1984	1	0	0	0	0	0	1	0	4	11	21	22	20	191	414	614	1188	1473	1370	833	400	177	60	31	20	3
1984	2	0	0	0	0	0	2	0	0	2	3	10	8	54	232	468	960	1290	1095	774	524	374	158	36	11	3
1984	3	0	0	0	0	0	0	1	2	12	53	250	643	1558	2738	6857	12095	15376	15438	12475	8243	4156	1555	465	143	43
1985	2	0	0	0	0	0	0	0	0	0	1	3	25	221	348	177	346	628	849	710	526	392	216	96	21	2
1985	3	0	0	0	0	0	1	0	0	5	28	167	756	5832	16308	14473	11108	18384	25332	19838	11750	6227	2938	1006	252	64
1986	1	0	0	0	0	0	0	0	7	23	51	84	278	1093	1464	1354	1181	2186	3783	3595	2082	911	360	107	26	3
1986	2	0	0	0	0	0	0	0	0	0	0	0	0	0	19	29	47	23	21	32	14	9	3	3	0	0
1986	3	0	0	0	0	0	0	0	0	0	18	154	610	2194	5080	14156	23223	20331	10705	10312	8875	4920	2286	869	324	85
1987	1	0	0	0	0	0	0	0	1	10	38	291	983	3411	3420	5818	10732	12540	10019	9453	7603	3871	1490	422	145	26
1987	3	0	0	0	3	0	0	0	2	7	26	130	511	4041	17126	27487	22822	24411	26687	19727	10159	6334	3638	1480	399	134

Table 2.8a–Length frequencies of Pacific cod in the 1989-1999 trawl fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1989	1	0	0	3	3	1	0	29	217	497	799	721	961	3128	4368	4678	5713	7070	8599	8291	6310	3853	1882	917	391	144
1989	2	0	0	0	0	0	0	0	0	1	0	4	3	20	68	109	136	142	79	39	9	1	0	1	0	0
1989	3	0	0	0	0	1	6	7	13	32	53	49	33	90	54	36	83	92	88	22	6	4	0	0	0	0
1990	1	0	0	3	4	14	85	312	710	953	888	715	539	1148	2576	4417	7339	9969	10306	9376	6405	4195	2266	1280	480	163
1990	2	0	0	0	0	0	0	0	2	2	6	6	17	106	377	772	1048	1631	1566	1623	1221	655	457	206	80	32
1990	3	0	0	0	0	0	0	0	0	1	2	14	42	13	30	17	16	49	17	19	16	10	0	2	0	2
1991	1	0	1	5	6	15	71	452	1230	1329	1232	1288	1713	5172	6133	6560	9202	12298	12683	10962	7771	5103	2937	1517	766	281
1991	2	1	0	1	1	2	2	7	9	16	32	25	27	103	129	216	251	300	319	219	200	136	62	18	1	6
1992	1	0	3	9	15	21	67	200	631	1310	1664	2488	4704	9607	7198	6648	6782	8239	8016	7777	5712	3853	2326	1291	517	208
1993	1	0	0	5	8	23	56	254	1164	1666	1780	4496	7742	11709	10367	9951	7408	5314	4343	3901	3540	3128	2163	1472	806	341
1994	1	0	1	5	5	24	106	610	2149	3791	3227	1938	2981	9909	14285	14434	11718	11710	9933	6337	4075	2739	1764	1161	623	314
1995	1	0	0	12	28	46	160	306	448	495	707	2597	5806	9110	5979	7066	8171	8721	7021	4381	2782	1824	1195	772	540	408
1996	1	1	6	13	25	29	51	382	1066	1319	1118	1145	2429	8755	14699	13711	9877	10959	11919	9647	6868	4308	2875	1607	911	575
1996	2	0	0	0	0	0	0	2	2	5	10	11	35	112	164	186	106	125	97	160	107	16	0	0	1	0
1996	3	0	0	0	0	0	0	1	0	3	1	13	51	132	149	275	322	292	287	305	436	454	388	220	104	40
1997	1	1	4	17	80	97	65	326	1261	2372	2398	1778	2027	7423	8553	11653	16352	16489	12167	7909	5444	4105	2800	1846	1060	620
1997	2	0	1	0	4	5	1	4	4	8	8	12	13	31	42	38	34	20	24	15	8	2	0	0	1	0
1998	1	0	1	7	4	7	114	744	1464	1423	1113	969	1398	5031	6020	6694	10192	14965	16533	10659	5972	3531	2880	2293	1631	1107
1998	2	0	0	0	0	1	0	0	1	31	61	71	47	110	242	298	270	195	125	83	36	12	9	5	10	6
1998	3	0	0	0	0	0	0	1	2	3	12	37	60	135	172	249	177	190	211	258	270	160	74	68	46	22
1999	1	4	0	1	6	5	10	108	421	412	382	1039	2515	5006	3143	3270	3992	5218	5560	4722	3617	2327	1295	818	592	382
1999	2	0	0	0	0	0	0	0	0	0	0	1	5	31	31	32	30	21	9	15	12	15	10	5	6	5
1999	3	0	0	0	0	0	0	0	2	1	0	2	18	51	114	164	145	144	121	96	88	82	53	36	14	5

Table 2.8b–Length frequencies of Pacific cod in the post-1999 trawl fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	0	0	0	2	2	7	63	187	173	236	559	1075	3035	4364	4870	4763	4839	5349	4673	3869	3230	2655	1546	952	636
2000	2	0	0	0	0	0	0	1	4	2	4	13	18	41	76	67	34	22	8	5	6	2	1	0	0	0
2000	3	0	0	0	0	0	0	0	0	0	0	0	0	3	13	20	12	8	6	3	0	1	1	0	0	0
2001	1	0	0	2	1	3	4	22	43	111	176	112	173	922	1483	2119	3376	4045	4026	2853	2193	1618	1195	840	531	276
2001	2	0	0	5	12	10	14	5	10	23	57	93	79	212	506	433	394	352	247	137	62	58	31	30	15	2
2001	3	0	0	0	0	0	1	2	8	12	8	21	33	80	109	200	199	202	175	109	68	33	15	14	10	5
2002	1	0	0	0	6	12	26	79	333	541	550	535	642	1780	2107	2215	3692	5123	5676	4771	3635	2621	1579	952	736	431
2002	2	0	0	0	6	8	3	12	68	201	263	306	288	417	596	747	529	399	253	195	147	69	42	20	10	4
2002	3	0	0	0	0	0	0	0	1	9	9	60	141	240	249	339	259	229	236	205	180	114	52	25	11	3
2003	1	0	0	2	4	1	2	5	82	266	333	355	647	1784	1864	2063	2746	3700	4237	3045	1798	895	379	170	78	30
2003	2	0	1	0	1	2	3	9	24	44	141	217	266	683	1106	1035	1046	1069	886	704	509	281	116	37	18	7
2003	3	0	0	0	0	0	0	0	0	0	1	7	31	94	190	200	221	225	246	237	232	156	92	35	7	1
2004	1	0	1	1	0	1	0	4	56	216	332	316	282	1295	2226	2490	2955	2947	2331	1575	998	535	339	197	113	48
2004	2	0	0	2	4	1	12	57	106	103	93	104	149	288	576	733	774	732	676	636	589	444	280	157	60	16
2004	3	0	0	0	0	0	0	0	0	0	0	0	3	10	21	42	54	82	107	85	76	33	28	14	1	0

Table 2.9a–Length frequencies of Pacific cod in the 1989-1999 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1990	1	0	0	0	0	0	0	0	0	0	0	4	12	163	784	1700	2796	3536	3080	2490	1599	1216	728	480	219	93
1990	2	0	0	0	0	0	0	6	6	24	56	136	238	794	2391	5893	10108	12945	12636	10237	7314	5084	3262	2200	889	315
1990	3	0	0	0	0	0	0	1	3	1	12	18	56	348	1644	5170	9453	11864	11121	8939	6057	3593	2102	1291	598	279
1991	1	0	0	0	0	0	0	0	5	14	30	114	306	1052	2487	5075	8929	11159	9547	6917	4040	2444	1331	780	311	130
1991	2	0	0	0	0	0	0	0	5	9	19	35	143	773	2130	4733	8310	10823	12060	10930	8769	6004	3203	1778	793	291
1991	3	0	0	0	1	3	18	33	39	62	127	207	467	1723	4038	7030	10634	13041	14086	13443	10791	7589	4290	2527	1104	440
1992	1	0	0	0	2	0	3	5	42	90	312	1253	3300	10451	14863	15640	19126	23004	20775	15837	11594	7556	4380	2455	1057	407
1992	2	0	0	0	0	3	2	3	21	66	174	574	1325	6719	13151	13754	15857	17833	16704	14043	11802	8990	6331	4035	2045	831
1992	3	0	0	0	0	0	0	0	1	6	19	52	154	765	2375	2564	2390	2741	2404	1939	1595	1267	888	565	298	106
1993	1	0	0	1	0	1	6	16	76	186	450	1482	3328	10312	20462	27089	23370	17302	14383	12020	9965	6845	3850	1953	926	314
1994	1	0	0	0	3	3	12	23	40	91	223	551	1472	7088	17414	29142	38186	32928	19177	9869	6051	4280	3011	1766	930	325
1994	3	0	0	0	0	0	0	2	8	12	57	145	268	952	3070	5831	8261	9569	7327	4226	2341	1425	914	505	296	141
1995	1	0	0	0	2	5	6	13	24	60	186	1059	3031	8219	14024	23789	30478	28823	18233	8432	3841	1961	1172	730	445	206
1995	2	0	0	0	0	0	0	0	0	0	1	0	3	10	33	55	79	56	29	37	38	27	15	9	0	0
1995	3	0	0	1	0	0	1	2	21	25	50	219	522	2929	7080	8279	9857	12273	11397	8717	5585	3365	2040	1402	714	287
1996	1	0	0	0	0	0	0	1	20	73	192	604	1794	9116	19703	26399	29777	28680	21120	12783	6741	3465	1691	992	518	382
1996	2	0	0	0	0	0	0	0	0	0	0	0	0	9	27	23	27	17	15	15	14	6	3	0	0	0
1996	3	0	0	0	0	0	1	0	4	15	83	182	404	1626	5549	11617	14477	11224	8332	7296	5950	4217	2391	1149	562	306
1997	1	0	0	0	0	0	1	5	18	92	224	571	1700	8606	17788	30652	40069	35267	21243	12004	7165	4417	2557	1322	651	389
1997	2	0	0	0	0	0	0	0	0	0	0	1	1	4	6	18	18	15	16	5	8	6	4	4	3	0
1997	3	0	0	1	2	3	13	20	89	160	288	621	1673	4814	9408	15198	20854	26965	25031	17322	8992	6074	3767	1977	853	364
1998	1	0	0	0	0	1	9	19	94	224	414	957	2524	8417	13159	18857	27872	30580	24229	13821	7243	4858	3787	2748	1747	1261
1998	2	0	0	0	0	0	0	0	0	0	1	1	6	22	4	9	7	4	1	2	3	0	2	0	0	0
1998	3	1	0	0	1	32	23	46	45	93	370	1928	4087	9736	15515	22466	26645	30947	28225	21358	13610	7212	3900	2469	1211	635
1999	1	0	0	0	2	2	0	4	22	60	220	1263	3731	8701	8787	10336	12449	12238	10724	7083	4170	2019	1037	624	408	347
1999	2	0	0	0	0	0	0	0	0	6	13	44	135	981	1548	1315	1398	1400	1230	816	573	328	175	77	42	14
1999	3	1	0	0	0	0	1	10	27	61	115	371	707	3684	7968	7048	6468	6890	6175	4308	3091	1886	1110	554	359	231

Table 2.9b–Length frequencies of Pacific cod in the post-1999 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	2	0	0	0	0	1	5	16	50	189	679	1627	6534	10526	11488	9991	8549	6638	4465	3133	2504	1923	1339	957	797
2000	2	0	0	0	0	0	0	0	0	0	4	10	27	248	654	1256	1910	1616	1240	891	701	500	397	250	156	100
2000	3	1	8	0	0	0	1	3	7	15	71	431	1300	4358	10130	16501	21226	16982	10164	6387	4077	2569	1573	881	569	443
2001	1	1	0	0	0	2	2	5	27	117	363	581	1283	5348	10260	14341	16442	13783	8606	4957	2958	1878	1393	955	705	552
2001	2	0	0	0	0	0	0	2	10	26	103	211	407	1449	3133	4343	4736	4615	3548	1825	1100	597	408	322	332	264
2001	3	0	0	0	1	4	0	5	21	56	236	1040	2147	6079	10320	16069	18724	18097	13810	6921	3436	1789	1248	960	679	593
2002	1	1	2	5	5	7	14	20	90	198	346	1104	2778	6505	7619	10662	14937	13802	9000	4165	1962	900	502	330	124	73
2002	2	0	0	0	0	1	2	3	27	74	189	328	637	2568	4552	5151	5247	5129	3579	2091	942	415	229	114	68	14
2002	3	2	0	0	0	0	2	17	49	164	428	1068	2283	7508	12276	13901	13729	12909	10164	5968	2954	1297	589	261	135	120
2003	1	0	0	2	0	3	1	9	40	233	528	1469	3627	10878	15728	16306	15084	13262	9552	4839	2150	775	312	123	53	14
2003	2	0	0	0	0	0	1	1	5	10	54	185	571	2478	5601	7083	6687	5653	4235	2311	1204	532	214	102	31	7
2003	3	1	0	0	0	0	0	0	4	23	91	269	1181	6401	13746	18801	18771	16306	12049	7757	4265	1892	740	287	116	42
2004	1	0	1	0	0	2	0	2	8	55	155	330	954	4834	10937	16754	18365	12760	6674	3390	1713	703	268	112	43	13
2004	2	0	0	0	0	0	0	0	0	2	11	26	113	604	1515	2664	3062	2962	2212	1367	888	443	204	61	25	4
2004	3	0	0	0	0	0	0	0	0	0	3	7	17	38	127	132	98	85	67	54	31	19	16	6	0	0

Table 2.10a–Length frequencies of Pacific cod in the 1989-1999 pot fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1990	2	0	0	0	0	0	0	0	0	0	0	0	1	7	42	74	141	230	293	220	229	138	81	45	3	2
1990	3	0	0	0	0	0	0	0	0	0	0	0	1	3	10	116	512	1149	1146	1360	701	391	260	109	11	3
1991	2	0	0	0	0	0	0	0	0	0	0	0	0	39	240	572	1106	1700	2050	1874	1636	875	414	155	35	5
1991	3	0	0	0	0	0	0	0	0	0	0	0	6	29	163	406	790	1444	2084	2236	1810	1218	637	290	101	29
1992	1	0	0	0	0	0	1	0	1	0	8	7	24	174	380	731	1875	3807	3583	2710	1776	1160	590	324	99	39
1992	2	0	0	0	0	0	0	1	2	5	36	103	438	2186	3592	4075	5205	6914	7708	7212	5139	3268	1601	710	261	113
1992	3	0	0	0	0	0	0	0	0	2	22	73	145	590	869	749	599	526	406	327	306	200	151	79	48	55
1993	1	0	0	0	0	0	0	0	0	0	0	8	28	320	824	1448	1968	1869	1621	1062	640	384	233	93	41	18
1994	1	0	0	0	0	0	0	0	0	0	1	19	125	727	2791	4384	4660	4567	3529	2371	1284	706	409	238	112	27
1994	3	0	0	0	0	0	0	0	0	5	3	10	25	152	576	1095	1255	1050	808	601	364	229	136	71	39	17
1995	1	0	0	0	0	0	0	0	0	1	4	45	242	1203	3094	6944	10101	9099	6435	3950	2408	1608	1394	826	222	84
1995	2	0	0	0	0	0	0	0	0	0	0	5	56	443	841	1540	2499	2682	2128	1816	1425	1139	1007	520	449	236
1995	3	0	0	0	0	0	0	0	0	0	1	0	16	275	821	1444	2240	2490	2142	1563	1158	787	449	201	125	29
1996	1	0	0	0	0	0	3	5	11	14	39	89	268	2272	6731	10936	13049	13395	10997	7115	4724	2883	1910	1123	588	241
1996	2	0	0	0	0	0	0	0	0	1	1	6	43	389	1293	2879	3807	3552	2788	2147	1939	1517	1126	771	513	291
1996	3	0	0	0	0	0	0	0	0	0	0	3	12	174	464	953	1766	1923	1526	1088	991	929	668	400	218	84
1997	1	0	0	0	0	1	0	0	1	3	15	38	82	647	2100	5113	9620	10616	6855	3690	1963	1239	838	530	311	197
1997	2	0	0	0	0	0	0	0	1	0	1	7	22	164	454	973	1685	2434	2523	1440	704	477	393	270	143	69
1997	3	0	0	0	0	0	0	0	1	0	1	7	22	164	454	973	1685	2434	2523	1440	704	477	393	270	143	69
1998	1	0	0	0	0	1	0	0	0	2	4	17	93	695	1363	2166	4743	6257	5386	3157	1369	579	372	213	118	60
1998	2	0	0	0	0	0	0	0	0	0	0	5	12	159	524	934	1372	1824	1709	1051	520	280	210	131	111	57
1998	3	0	0	0	0	0	0	0	1	0	3	8	10	70	257	405	605	730	788	587	396	247	147	130	72	66
1999	1	0	0	0	0	0	0	1	2	2	6	17	106	918	1497	2389	3677	3882	3557	2484	1586	958	656	392	332	172
1999	2	0	0	0	0	0	0	0	0	0	0	2	7	58	123	151	239	239	257	198	170	148	116	72	51	44
1999	3	0	0	0	0	0	0	0	0	4	12	21	53	305	793	1153	1122	1255	1086	835	696	585	442	249	202	109

Table 2.10b–Length frequencies of Pacific cod in the post-1999 pot fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	0	0	0	0	0	0	0	1	2	2	12	112	934	2545	4019	4085	3753	3482	2412	1715	1125	882	487	256	216
2000	3	0	0	0	0	0	0	0	0	0	1	1	3	39	87	134	149	62	25	8	0	2	1	0	0	0
2001	1	4	0	1	0	0	0	0	0	0	0	3	13	234	796	2200	4015	4021	2277	1046	485	316	232	168	78	96
2001	2	0	0	0	0	0	0	0	0	0	0	0	0	0	12	45	77	103	93	61	33	5	7	4	6	1
2001	3	0	0	0	0	0	0	2	2	1	4	4	14	155	618	1313	1543	1768	1322	674	438	267	156	93	48	25
2002	1	0	0	0	0	0	0	0	0	0	1	4	16	131	605	1564	2847	2848	1789	768	297	134	78	39	20	14
2002	2	0	0	0	0	0	0	0	0	0	0	1	2	3	20	45	72	65	62	41	32	9	12	2	0	1
2002	3	0	0	0	0	0	1	0	0	0	0	5	26	165	580	1244	1352	1026	728	485	314	144	107	43	19	11
2003	1	0	0	0	0	0	0	0	2	3	3	6	54	267	766	1391	2203	2788	2360	1328	655	259	97	41	19	9
2003	3	0	0	0	0	0	0	0	0	1	0	2	19	236	920	1472	1403	1227	951	607	449	291	153	60	26	4
2004	1	0	0	0	0	0	0	0	0	0	0	1	15	253	895	1493	1870	1709	1185	668	375	188	105	43	17	5
2004	2	0	0	0	0	0	0	0	0	0	0	0	0	2	22	53	56	60	46	32	15	16	18	3	0	0
2004	3	0	0	0	0	0	0	1	2	2	1	1	8	25	149	246	213	129	82	60	70	41	35	20	10	2

Table 2.11a–Length frequencies of Pacific cod in the trawl survey by year (all surveys take place in period 2). Numbers shown are survey estimates of population numbers at length, rescaled so that the sum equals the total size of the actual survey length sample.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1979	2	0	5	44	186	374	457	694	1764	2393	1884	1171	618	202	70	44	51	29	8	0	3	1	1	0	0	0
1980	2	0	6	85	241	82	42	224	687	929	1320	1542	2062	1364	893	333	100	33	31	19	6	2	0	0	0	0
1981	2	0	20	156	330	278	32	100	330	653	724	511	1063	1396	1746	1215	812	398	156	39	27	13	1	0	0	0
1982	2	16	84	205	132	35	27	124	384	732	718	391	769	1179	1256	1232	1135	821	450	192	80	26	8	3	0	0
1983	2	278	996	939	460	109	23	100	264	405	294	163	483	891	1024	1069	891	700	514	247	111	22	14	3	1	0
1984	2	43	88	66	120	252	762	1380	1426	858	389	200	291	361	481	708	783	713	478	320	152	83	36	10	1	0
1985	2	88	325	573	893	1004	387	179	362	544	580	703	1194	815	392	282	322	408	401	294	148	69	24	10	4	0
1986	2	91	286	320	99	75	452	1163	1257	1040	711	359	396	573	869	776	406	268	296	244	171	79	48	13	8	0
1987	2	18	72	248	385	258	179	413	847	729	580	600	1231	1089	768	551	604	581	378	193	151	61	45	15	6	0
1988	2	9	53	80	91	109	236	282	393	666	627	493	987	1102	1310	1086	833	559	414	293	234	75	33	28	7	0
1989	2	17	137	316	224	69	37	92	102	147	350	347	565	709	1218	1308	1138	941	800	632	326	234	146	87	59	0
1990	2	203	491	689	357	132	124	263	303	323	277	174	160	169	224	349	408	276	262	170	123	82	33	25	10	1
1991	2	141	408	447	381	228	262	595	867	912	611	349	249	259	327	260	226	211	181	108	107	49	20	22	7	1
1992	2	18	468	451	565	514	455	891	1092	872	560	462	889	699	564	244	233	186	108	101	91	54	38	30	15	1
1993	2	114	924	1087	981	677	213	247	614	847	666	489	845	842	665	398	267	230	85	62	49	36	21	24	15	6
1994	2	18	145	291	361	327	446	957	1924	2082	1121	443	685	1051	964	1058	920	565	288	92	46	33	60	15	22	8
1995	2	29	74	135	208	77	172	460	691	580	705	1064	1575	1017	617	434	484	326	253	133	84	41	27	18	9	3
1996	2	14	65	164	198	110	103	357	699	677	526	499	744	1477	1404	908	499	288	237	148	109	71	25	16	7	3
1997	2	91	472	601	728	507	140	215	481	628	451	407	399	918	809	842	583	436	215	105	60	40	26	10	4	1
1998	2	30	262	334	74	46	311	1151	1837	1396	655	379	367	659	458	378	391	333	244	132	64	33	29	9	10	1
1999	2	71	335	286	113	141	415	760	874	667	719	1169	1648	1854	768	493	447	337	252	130	89	62	37	24	7	2
2000	2	175	918	1310	505	54	141	488	785	604	564	749	958	1720	1419	894	537	266	188	99	79	57	33	19	3	0
2001	2	95	640	1815	2110	1011	407	903	1994	2550	1618	706	486	1193	1278	1080	819	515	257	123	71	34	22	14	4	5
2002	2	31	192	374	352	105	207	662	1456	1446	1004	791	1216	1579	880	611	546	368	209	104	49	19	16	15	3	2
2003	2	19	283	635	774	682	489	182	255	705	837	974	1188	1969	1213	767	513	338	259	141	86	35	14	2	1	0
2004	2	24	275	483	562	318	218	484	729	930	978	711	578	805	926	845	715	475	286	211	111	82	34	15	5	4

Table 2.11b–Age composition estimates from the 1998-2003 EBS bottom trawl surveys (expressed as numbers per 10,000).

AGE	1998	1999	2000	2001	2002	2003
1	705	757	2330	2911	832	1744
2	4526	2011	1149	2365	1860	1590
3	2011	3111	1656	1966	3085	2467
4	1132	2377	2447	900	2437	2143
5	586	791	1544	877	741	1183
6	593	542	588	673	573	400
7	283	269	107	227	382	282
8	140	98	118	54	64	146
9	22	36	28	14	18	32
10	0	0	26	9	6	3
11	2	7	7	6	0	3
12+	0	0	0	1	1	7

Table 2.11c–Length frequencies of Pacific cod in the EBS slope bottom trawl survey by year (all surveys take place in period 2). Numbers shown are survey estimates of population numbers at length, rescaled so that the sum equals the total size of the actual survey length sample.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2002	2	0	0	0	0	0	0	0	0	1	0	5	18	69	105	86	62	55	39	21	7	1	0	0	0	0
2004	2	0	0	0	0	0	0	0	0	0	1	1	2	32	94	114	128	93	44	10	7	3	2	0	0	0

Table 2.12–Biomass, standard error, 95% confidence interval (CI), and population numbers of Pacific cod estimated by NMFS' annual bottom trawl survey of the EBS shelf. All figures except population numbers are expressed in metric tons. Population numbers are expressed in terms of individual fish.

Year	Biomass	Standard Error	Lower 95% CI	Upper 95% CI	Numbers
1979	754,314	97,844	562,539	946,089	1,530,429,650
1980	905,344	87,898	733,063	1,077,624	1,084,147,540
1981	1,034,629	123,849	791,885	1,277,373	794,619,624
1982	1,020,550	73,392	876,701	1,164,399	583,715,089
1983	1,176,305	121,606	937,958	1,414,651	725,351,369
1984	1,001,940	64,127	876,251	1,127,629	636,948,300
1985	961,050	51,453	860,203	1,061,896	800,070,473
1986	1,134,106	71,813	993,353	1,274,858	843,460,794
1987	1,142,450	71,439	1,002,430	1,282,468	754,269,021
1988	959,544	76,284	810,028	1,109,060	509,336,483
1989	960,436	69,157	824,888	1,095,984	339,719,445
1990	708,551	53,728	603,245	813,857	435,856,535
1991	532,590	41,678	450,902	614,279	496,841,261
1992*	546,707	45,754	457,030	636,383	577,416,832
1993	690,524	54,934	582,853	798,196	851,866,426
1994	1,368,109	254,435	869,416	1,866,802	1,237,760,162
1995	1,003,046	92,677	821,400	1,184,692	757,576,445
1996	890,793	120,522	652,160	1,129,426	609,304,214
1997	604,881	69,250	466,382	743,380	487,429,700
1998	534,141	42,942	449,116	619,166	514,321,475
1999	583,259	50,622	483,028	683,490	500,692,872
2000	528,466	43,037	443,253	613,679	481,358,109
2001	833,272	76,267	680,739	985,805	984,379,812
2002	620,520	69,046	482,428	758,612	567,926,526
2003	605,681	63,601	478,479	732,882	510,187,323
2004	596,988	35,135	527,421	666,556	424,265,173

*During the 1992 field season, 18 stations were omitted from the standard survey grid due to severe weather and vessel problems. In 1989, 1990, and 1991, these 18 stations represented, on average, 2.2% and 2.8% of the total Pacific cod biomass and numbers, respectively. The 1992 point estimates and confidence interval shown above have been adjusted upward proportionately.

Table 2.13–Symbols used in the Synthesis assessment model for Pacific cod (page 1 of 2).

Indices	
a	age group
g	gear type
i	time interval
j	size bin
y	year

Dimensions	
a_{min}	age of youngest group
a_{max}	age of oldest group
g_{max}	number of gear types
i_{max}	number of time intervals in each year
j_{max}	number of size bins
y_{max}	number of years

Special Values of Indices	
a_{rec}	index of age group used to assess recruitment strength
g_{sur}	index of survey gear type
i_{spa}	index of time interval during which spawning occurs
i_{sur}	index of time interval during which survey occurs

Operators	
$e(y \mid g)$	returns the era containing year y given gear type g
l_{mid}	returns the length corresponding to the midpoint of bin j
l_{min}	returns the smallest length contained in bin j
t_{dur}	returns the duration (in years) of time interval i

Continuous Variables	
α	age
λ	length
τ	time

Special Values of Continuous Variables	
α_1	first reference age used in length-at-age relationship (in years)
α_2	second reference age used in length-at-age relationship (in years)
λ_{min}	minimum length used in assessment
λ_{max}	maximum length used in assessment
τ_{spa}	annual time of spawning (in years)
τ_{sur}	annual time of survey (in years)

Table 2.13–Symbols used in the Synthesis assessment model for Pacific cod (page 2 of 2).

Functions of Age or Length	
$h(\lambda \mid \alpha)$	probability density function describing distribution of length, conditional on age
$l(\alpha)$	length at age
$p(\lambda)$	proportion mature at length
$s(\lambda \mid g, y)$	selectivity at length, conditional on gear type and year
$w(\lambda)$	weight at length
$x(\alpha)$	standard deviation associated with the length-at-age relationship, as a function of age

Arrays Generated by Synthesis	
b_y	biomass of population aged $a \geq a_{rec}$ at start of year y
c_y	spawning biomass at time of spawning in year y
d_y	survey biomass at time of survey in year y
$n_{a,y,i}$	population numbers at age a, year y, and time interval i
$u_{a,y}$	population numbers at time of spawning at age a and year y
$v_{a,y}$	population numbers at time of survey at age a and year y
$z_{a,i,j}$	proportion of length distribution falling within size bin j at age a and time interval i

Parameters Used by Synthesis	
$F_{g,y,i}$	instantaneous fishing mortality rate at each gear g, year y, and time i for which catch>0
K	Brody's growth parameter
L_1	length at age α_1
L_2	length at age α_2
M	instantaneous natural mortality rate
N_a	initial population numbers at each age $a > a_{min}$
P_1	length at point of inflection in maturity schedule
P_2	relative slope at point of inflection in maturity schedule
Q	survey catchability
R_y	recruitment at age a_{min} in year y
$S_{1,g,e(y\mid g)}$	selectivity at minimum length in gear type g and era e
$S_{2,g,e(y\mid g)}$	length at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{3,g,e(y\mid g)}$	relative slope at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{4,g,e(y\mid g)}$	length at maximum selectivity in gear type g and era e
$S_{5,g,e(y\mid g)}$	selectivity at maximum length in gear type g and era e
$S_{6,g,e(y\mid g)}$	length at inflection in descending part of selectivity schedule in gear type g and era e
$S_{7,g,e(y\mid g)}$	relative slope at inflection in descending part of selectivity schedule in gear type g and era e
W_1	weight-length proportionality
W_2	weight-length exponent
X_1	standard deviation of length evaluated at age α_1
X_2	standard deviation of length evaluated at age α_2

Table 2.14–Dimensions and special values of indices and variables used in the Pacific cod assessment. Symbols are defined in Table 2.13.

Dimensions

Term	Value	Comments/Rationale
a_{min}	1	assumed minimum age group observed in the trawl survey
a_{max}	12	a convenient place to insert an “age-plus” category
g_{max}	6	early trawl, late trawl, longline, pot, pre-1982 survey, post-1981 survey
i_{max}	3	January through March, June through August, September through December
j_{max}	25	bin boundaries are given in the “Data” section of the text
y_{max}	26	1978 through 2004

Special Values of Indices

Term	Value	Comments/Rationale
a_{rec}	3	age traditionally used to indicate first significant recruitment to the fishery
g_{sur}	6	index of post-1981 survey gear type
i_{spa}	1	March (see τ_{spa} below) falls within the first intra-annual time period
i_{sur}	2	July (see τ_{sur} below) falls within the second intra-annual time period

Special Values of Continuous Variables

Term	Value	Comments/Rationale
α_1	1.5	assumed age of youngest fish seen in the trawl survey
α_2	12.0	set equal to the lower bound of the age-plus group for convenience
λ_{min}	9	close to the length of the smallest fish seen by the survey in a typical year
λ_{max}	115	close to the length of the largest fish seen by the survey in a typical year
τ_{spa}	(3-1)/12	March appears to be the month of peak spawning in the observer data
τ_{sur}	(7-1)/12	July is the approximate mid-point of the June-August trawl survey season

Table 2.15–Partitioning the list of parameters used in the Synthesis model of Pacific cod into those that are estimated independently (i.e., outside) of Synthesis and those that are estimated conditionally (i.e., inside of Synthesis).

Parameters Estimated Independently

L_1	length at age α_1
M	instantaneous natural mortality rate
P_1	length at point of inflection in maturity schedule
P_2	relative slope at point of inflection in maturity schedule
Q	survey catchability
W_1	weight-length proportionality
W_2	weight-length exponent
X_1	standard deviation of length evaluated at age α_1
X_2	standard deviation of length evaluated at age α_2

Parameters Estimated Conditionally

$F_{g,y,i}$	instantaneous fishing mortality rate at each gear g, year y, and time i for which catch>0
K	Brody's growth parameter
L_2	length at age α_2
N_a	initial population numbers at each age $a > a_{min}$
R_y	recruitment at age a_{min} in year y
$S_{1,g,e(y\|g)}$	selectivity at minimum length in gear type g and era e
$S_{2,g,e(y\|g)}$	length at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{3,g,e(y\|g)}$	relative slope at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{4,g,e(y\|g)}$	length at maximum selectivity in gear type g and era e
$S_{5,g,e(y\|g)}$	selectivity at maximum length in gear type g and era e
$S_{6,g,e(y\|g)}$	length at inflection in descending part of selectivity schedule in gear type g and era e
$S_{7,g,e(y\|g)}$	relative slope at inflection in descending part of selectivity schedule in gear type g and era e

Table 2.16–Pacific cod commercial fishery length sample sizes used in the multinomial distribution. (These values correspond to the square roots of the true sample sizes shown in Table 2.5.)

Year	Trawl Fishery			Longline Fishery			Pot Fishery		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	25	0	56	54	70	50	0	0	0
1979	41	0	27	107	50	52	0	0	0
1980	37	9	18	51	37	54	0	0	0
1981	11	0	39	47	36	36	0	0	0
1982	24	15	41	54	35	71	0	0	0
1983	111	35	121	137	64	98	0	0	0
1984	101	67	67	83	77	287	0	0	0
1985	174	39	55	0	68	367	0	0	0
1986	169	43	50	136	14	323	0	0	0
1987	215	82	145	265	0	406	0	0	0
1988	322	0	54	0	0	0	0	0	0
1989	242	25	26	0	0	0	0	0	0
1990	253	99	16	137	273	250	0	39	76
1991	298	46	0	234	266	303	0	103	106
1992	282	0	0	390	366	142	131	220	72
1993	286	0	0	393	0	0	103	0	0
1994	322	0	0	415	0	213	161	0	80
1995	262	0	0	380	20	273	218	130	117
1996	323	34	59	405	12	275	276	152	106
1997	327	17	0	430	10	380	209	108	108
1998	329	53	55	404	8	437	163	94	67
1999	212	15	34	290	100	226	150	43	94
2000	217	17	8	267	100	313	161	0	23
2001	162	53	36	291	166	320	126	21	92
2002	195	68	49	274	177	293	106	19	79
2003	156	91	44	308	192	321	111	0	88
2004	139	81	24	279	127	26	94	18	33

Table 2.17–Time series of EBS Pacific cod age 3+ biomass, spawning biomass, and survey biomass as estimated by Models 1 and 2. The biomass time series obtained by the survey is shown in the right-hand column ("Survey (obs)") for comparison. All biomass figures are in 1000s of t.

	Age 3+ Biomass		Spawning Biomass		Survey Biomass		
Year	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Survey (obs)
1978	394	435	48	40	n/a	n/a	n/a
1979	676	732	79	65	567	657	754
1980	1151	1145	136	113	906	958	905
1981	1664	1547	249	202	1061	1133	1035
1982	2093	1862	422	333	1217	1145	1021
1983	2367	2066	593	465	1147	1114	1176
1984	2497	2174	707	554	1106	1122	1002
1985	2560	2237	747	588	1132	1134	961
1986	2580	2264	747	590	1118	1138	1134
1987	2605	2281	750	592	1135	1127	1142
1988	2565	2224	744	591	1037	1016	960
1989	2379	2040	724	572	871	862	960
1990	2142	1844	696	550	717	750	709
1991	1915	1682	628	497	656	717	533
1992	1731	1548	530	419	699	733	547
1993	1665	1505	461	366	730	750	691
1994	1670	1518	442	353	745	771	1368
1995	1648	1488	427	341	726	727	1003
1996	1538	1371	406	322	641	641	891
1997	1405	1249	387	304	544	563	605
1998	1249	1115	352	275	523	549	534
1999	1206	1080	320	250	556	560	583
2000	1198	1076	300	233	569	572	528
2001	1210	1091	300	231	597	611	833
2002	1268	1141	302	233	654	650	621
2003	1313	1168	304	233	670	653	606
2004	1315	1155	317	239	617	608	597

Table 2.18–Estimates of Pacific cod fishing mortality rates, expressed on an annual time scale. Empty cells indicate that no catch was recorded.

Year	Trawl			Longline			Pot		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	0.15	0.31	0.34	0.03	0.03	0.03			
1979	0.09	0.22	0.12	0.02	0.01	0.01			
1980	0.05	0.09	0.11	0.01	0.00	0.03			
1981	0.05	0.08	0.08	0.00	0.00	0.01			
1982	0.05	0.07	0.04	0.00	0.00	0.01			
1983	0.07	0.07	0.05	0.01	0.00	0.01			
1984	0.08	0.07	0.05	0.01	0.01	0.04			
1985	0.09	0.08	0.05	0.02	0.01	0.05			
1986	0.10	0.08	0.05	0.02	0.00	0.04			
1987	0.10	0.04	0.05	0.04	0.00	0.06			
1988	0.21	0.07	0.10	0.00	0.00	0.00			
1989	0.21	0.05	0.04	0.01	0.01	0.01	0.00	0.00	0.00
1990	0.18	0.03	0.02	0.02	0.05	0.04		0.00	0.00
1991	0.21	0.05	0.02	0.05	0.09	0.09	0.00	0.00	0.01
1992	0.14	0.05	0.02	0.13	0.11	0.02	0.01	0.02	0.00
1993	0.17	0.02	0.03	0.14	0.00	0.00	0.01	0.00	
1994	0.15	0.02	0.06	0.15	0.00	0.07	0.01		0.01
1995	0.23	0.04	0.04	0.18	0.00	0.10	0.03	0.02	0.01
1996	0.20	0.01	0.04	0.17	0.00	0.10	0.05	0.03	0.01
1997	0.23	0.02	0.03	0.20	0.00	0.19	0.04	0.02	0.01
1998	0.14	0.03	0.04	0.18	0.00	0.14	0.03	0.02	0.01
1999	0.16	0.02	0.02	0.21	0.01	0.12	0.04	0.01	0.01
2000	0.23	0.03	0.03	0.16	0.01	0.20	0.07		0.00
2001	0.12	0.05	0.03	0.14	0.04	0.21	0.05	0.00	0.02
2002	0.19	0.07	0.02	0.18	0.08	0.18	0.04	0.00	0.02
2003	0.18	0.07	0.02	0.19	0.07	0.19	0.06	0.00	0.03
2004	0.21	0.08	0.02	0.19	0.06	0.18	0.05	0.00	0.02

Table 2.19–Estimates of Pacific cod recruitment at age 1 and initial numbers at age (in millions of fish).

Year	Recruitment at age 1
1978	1176
1979	615
1980	906
1981	214
1982	829
1983	964
1984	566
1985	933
1986	397
1987	256
1988	223
1989	604
1990	793
1991	453
1992	596
1993	606
1994	235
1995	285
1996	479
1997	576
1998	360
1999	463
2000	752
2001	471
2002	357
2003	260
2004	377

Age	Numbers at age
2	1084
3	0
4	159
5	45
6	0
7	10
8	1
9	0
10	0
11	0
12	0

Table 2.20–Estimates of Pacific cod selectivity parameters. The first column lists the parameter families for which the remaining columns contain era-specific estimates (in the "Survey" portion of the table, the second and third columns contain the era-specific estimates for the shelf survey and the fourth column contains the estimates for the slope survey).

Trawl (Jan-May)	1978-88	1989-99	2000-04
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	57.15	58.20	71.47
$S_{3,g,e(y\|g)}$	0.14	0.14	0.14
$S_{4,g,e(y\|g)}$	87.40	94.10	110.47
$S_{5,g,e(y\|g)}$	0.41	0.64	0.94
$S_{6,g,e(y\|g)}$	88.23	94.56	110.70
$S_{7,g,e(y\|g)}$	0.12	0.00	4.57
Trawl (Jun-Dec)	1978-88	1989-99	2000-04
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	62.67	57.57	63.71
$S_{3,g,e(y\|g)}$	0.16	0.17	0.13
$S_{4,g,e(y\|g)}$	98.02	109.01	104.72
$S_{5,g,e(y\|g)}$	0.60	0.61	0.28
$S_{6,g,e(y\|g)}$	98.02	109.01	104.95
$S_{7,g,e(y\|g)}$	0.00	0.00	0.00
Longline	1978-88	1989-99	2000-04
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	60.89	57.98	56.88
$S_{3,g,e(y\|g)}$	0.23	0.26	0.25
$S_{4,g,e(y\|g)}$	85.09	78.63	78.98
$S_{5,g,e(y\|g)}$	0.22	0.46	0.63
$S_{6,g,e(y\|g)}$	85.75	115.00	79.79
$S_{7,g,e(y\|g)}$	0.07	0.00	0.30
Pot	1978-88	1989-99	2000-04
$S_{1,g,e(y\|g)}$	n/a	0.00	0.00
$S_{2,g,e(y\|g)}$	n/a	61.63	60.45
$S_{3,g,e(y\|g)}$	n/a	0.26	0.30
$S_{4,g,e(y\|g)}$	n/a	83.83	76.36
$S_{5,g,e(y\|g)}$	n/a	0.57	0.60
$S_{6,g,e(y\|g)}$	n/a	84.54	77.24
$S_{7,g,e(y\|g)}$	n/a	0.00	0.14
Survey	1978-81	1982-04	Slope
$S_{1,g,e(y\|g)}$	0.00	0.12	0.00
$S_{2,g,e(y\|g)}$	36.99	35.89	52.53
$S_{3,g,e(y\|g)}$	0.16	0.11	0.50
$S_{4,g,e(y\|g)}$	36.99	35.89	52.53
$S_{5,g,e(y\|g)}$	0.00	0.11	0.55
$S_{6,g,e(y\|g)}$	37.96	35.89	52.53
$S_{7,g,e(y\|g)}$	0.00	0.03	0.00

Table 2.21–Distribution of Pacific cod lengths (in cm) at age (mid-year) as defined by final parameter estimates. Lengths correspond to lower bounds of size bins. Columns sum to 1.0.

Len.	Age Group											
	1	2	3	4	5	6	7	8	9	10	11	12+
105	0	0	0	0	0	0	0	0	0.002	0.013	0.039	0.241
100	0	0	0	0	0	0	0	0.002	0.012	0.040	0.085	0.170
95	0	0	0	0	0	0	0.001	0.011	0.047	0.107	0.167	0.189
90	0	0	0	0	0	0	0.007	0.046	0.123	0.195	0.232	0.168
85	0	0	0	0	0	0.003	0.036	0.126	0.215	0.245	0.224	0.119
80	0	0	0	0	0	0.019	0.113	0.225	0.252	0.210	0.152	0.067
75	0	0	0	0	0.005	0.079	0.222	0.261	0.198	0.124	0.072	0.031
70	0	0	0	0	0.033	0.195	0.274	0.196	0.104	0.050	0.024	0.011
65	0	0	0	0.004	0.125	0.286	0.210	0.096	0.037	0.014	0.006	0.003
60	0	0	0	0.036	0.264	0.247	0.101	0.030	0.009	0.003	0.001	0.001
55	0	0	0.001	0.152	0.304	0.126	0.030	0.006	0.001	0	0	0
50	0	0	0.020	0.310	0.191	0.038	0.006	0.001	0	0	0	0
45	0	0	0.128	0.308	0.065	0.007	0.001	0	0	0	0	0
42	0	0	0.179	0.109	0.010	0.001	0	0	0	0	0	0
39	0	0.004	0.231	0.053	0.003	0	0	0	0	0	0	0
36	0	0.023	0.212	0.020	0.001	0	0	0	0	0	0	0
33	0	0.082	0.138	0.006	0	0	0	0	0	0	0	0
30	0	0.187	0.064	0.001	0	0	0	0	0	0	0	0
27	0	0.267	0.021	0	0	0	0	0	0	0	0	0
24	0.001	0.240	0.005	0	0	0	0	0	0	0	0	0
21	0.014	0.135	0.001	0	0	0	0	0	0	0	0	0
18	0.085	0.048	0	0	0	0	0	0	0	0	0	0
15	0.241	0.011	0	0	0	0	0	0	0	0	0	0
12	0.337	0.002	0	0	0	0	0	0	0	0	0	0
9	0.321	0	0	0	0	0	0	0	0	0	0	0

Table 2.22–Schedules of Pacific cod weight (kg) and maturity proportions at length (cm) as defined by final parameter estimates. Lengths correspond to lower bounds of size bins.

Bin	Length	Weight	Maturity
1	9	0.010	0.000
2	12	0.021	0.001
3	15	0.040	0.001
4	18	0.068	0.001
5	21	0.107	0.002
6	24	0.160	0.003
7	27	0.229	0.004
8	30	0.317	0.006
9	33	0.425	0.010
10	36	0.556	0.015
11	39	0.713	0.023
12	42	0.898	0.035
13	45	1.201	0.061
14	50	1.659	0.117
15	55	2.225	0.210
16	60	2.912	0.347
17	65	3.735	0.514
18	70	4.705	0.678
19	75	5.838	0.808
20	80	7.146	0.894
21	85	8.645	0.945
22	90	10.348	0.972
23	95	12.271	0.986
24	100	14.428	0.993
25	105	15.566	0.995

Table 2.23a–Schedules of Pacific cod selectivities in the commercial fisheries as defined by final parameter estimates. Lengths (cm) correspond to lower bounds of size bins.

Bin	Len.	Trawl (Jan.-May)			Trawl (Jun.-Dec.)			Longline			Pot	
		78-88	89-99	00-04	78-88	89-99	00-04	78-88	89-99	00-05	89-99	00-04
1	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	18	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	21	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
6	24	0.02	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
7	27	0.03	0.02	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
8	30	0.04	0.04	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00
9	33	0.06	0.06	0.01	0.02	0.03	0.03	0.00	0.01	0.01	0.00	0.00
10	36	0.09	0.08	0.02	0.03	0.05	0.05	0.01	0.01	0.02	0.00	0.00
11	39	0.13	0.12	0.03	0.05	0.09	0.07	0.02	0.02	0.03	0.01	0.01
12	42	0.19	0.17	0.04	0.07	0.14	0.10	0.04	0.05	0.07	0.02	0.02
13	45	0.26	0.24	0.06	0.12	0.21	0.15	0.07	0.10	0.14	0.05	0.04
14	50	0.42	0.38	0.11	0.23	0.38	0.25	0.20	0.30	0.36	0.15	0.16
15	55	0.59	0.55	0.19	0.40	0.58	0.39	0.45	0.61	0.66	0.39	0.46
16	60	0.75	0.71	0.32	0.60	0.76	0.55	0.72	0.85	0.88	0.71	0.80
17	65	0.87	0.84	0.48	0.77	0.88	0.70	0.89	0.96	0.97	0.90	0.96
18	70	0.94	0.92	0.65	0.89	0.95	0.82	0.97	0.99	0.99	0.98	1.00
19	75	0.98	0.96	0.79	0.95	0.98	0.90	0.99	0.95	0.88	1.00	0.87
20	80	1.00	0.99	0.88	0.98	0.99	0.95	0.93	0.87	0.71	0.95	0.76
21	85	0.82	1.00	0.94	0.99	1.00	0.98	0.75	0.79	0.65	0.88	0.69
22	90	0.66	0.92	0.97	0.99	1.00	0.99	0.59	0.71	0.64	0.80	0.64
23	95	0.54	0.83	0.99	0.86	1.00	1.00	0.44	0.63	0.63	0.72	0.62
24	100	0.46	0.73	1.00	0.73	0.97	0.67	0.32	0.54	0.63	0.65	0.60
25	105	0.41	0.64	0.94	0.60	0.61	0.28	0.22	0.46	0.63	0.57	0.60

Table 2.23b–Schedules of Pacific cod selectivities in the bottom trawl surveys as defined by final parameter estimates. Lengths (cm) correspond to lower bounds of size bins.

Bin	Len.	Shelf		Slope
		78-81	82-04	01-03
1	9	0.00	0.12	0.00
2	12	0.02	0.17	0.00
3	15	0.05	0.23	0.00
4	18	0.11	0.31	0.00
5	21	0.19	0.41	0.00
6	24	0.30	0.53	0.00
7	27	0.46	0.67	0.00
8	30	0.66	0.82	0.00
9	33	0.89	0.98	0.00
10	36	0.98	0.96	0.01
11	39	0.93	0.91	0.02
12	42	0.89	0.86	0.10
13	45	0.85	0.81	0.37
14	50	0.78	0.74	0.99
15	55	0.71	0.66	0.95
16	60	0.64	0.59	0.91
17	65	0.57	0.52	0.87
18	70	0.50	0.45	0.83
19	75	0.42	0.39	0.79
20	80	0.35	0.33	0.75
21	85	0.28	0.28	0.71
22	90	0.21	0.23	0.67
23	95	0.14	0.19	0.63
24	100	0.07	0.15	0.59
25	105	0.00	0.11	0.55

Table 2.24–Time series of EBS Pacific cod age 3+ biomass, spawning biomass, and survey biomass as estimated in last year's and this year's assessments.

Year	Age 3+ Biomass		Spawning Biomass		Survey Biomass	
	Last Year	This Year	Last Year	This Year	Last Year	This Year
1978	324	435	48	40	n/a	n/a
1979	480	732	80	65	558	657
1980	1066	1145	138	113	921	958
1981	1593	1547	257	202	1062	1133
1982	2073	1862	440	333	1208	1145
1983	2410	2066	620	465	1135	1114
1984	2450	2174	742	554	1094	1122
1985	2608	2237	786	588	1122	1134
1986	2573	2264	789	590	1108	1138
1987	2647	2281	793	592	1127	1127
1988	2640	2224	789	591	1033	1016
1989	2482	2040	775	572	866	862
1990	2223	1844	744	550	710	750
1991	1938	1682	672	497	648	717
1992	1746	1548	568	419	694	733
1993	1698	1505	493	366	728	750
1994	1674	1518	475	353	746	771
1995	1694	1488	458	341	732	727
1996	1600	1371	440	322	650	641
1997	1466	1249	422	304	554	563
1998	1274	1115	387	275	537	549
1999	1256	1080	354	250	574	560
2000	1255	1076	335	233	585	572
2001	1241	1091	337	231	607	611
2002	1289	1141	341	233	670	650
2003	1393	1168	343	233	695	653
2004	n/a	1155	n/a	239	n/a	608

Notes: Spawning biomass is computed as the sum of March female numbers at age times population weight at age times fraction mature at age.

"Survey biomass" is the model's estimate of what the actual survey should have observed.

All biomass figures are in 1000s of t.

Table 2.25–Time series of EBS Pacific cod age 3 recruitment as estimated in last year's and this year's assessments.

Year	Recruitment (millions of age 3 fish)	
	Last Year	This Year
1978	93	0
1979	177	747
1980	705	560
1981	319	293
1982	365	432
1983	287	102
1984	94	395
1985	523	460
1986	157	270
1987	420	445
1988	257	189
1989	158	122
1990	91	106
1991	119	288
1992	285	378
1993	277	216
1994	162	284
1995	308	289
1996	151	112
1997	123	136
1998	118	228
1999	264	274
2000	175	172
2001	155	221
2002	248	358
2003	311	224
2004	n/a	170

Table 2.26–Time series of EBS Pacific cod catch divided by age 3+ biomass as estimated in last year's and this year's assessments (the last entry in each column is based on partial catches for the respective year, because the year was/is still in progress at the time of the assessment).

Year	EBS Catch Divided by Age 3+ Biomass	
	Last Year	This Year
1978	0.13	0.10
1979	0.07	0.05
1980	0.04	0.04
1981	0.04	0.04
1982	0.03	0.03
1983	0.04	0.05
1984	0.05	0.06
1985	0.06	0.06
1986	0.05	0.06
1987	0.06	0.07
1988	0.08	0.09
1989	0.07	0.09
1990	0.08	0.09
1991	0.11	0.12
1992	0.09	0.11
1993	0.08	0.09
1994	0.10	0.11
1995	0.13	0.15
1996	0.13	0.15
1997	0.16	0.19
1998	0.12	0.14
1999	0.12	0.14
2000	0.12	0.14
2001	0.11	0.13
2002	0.13	0.15
2003	0.10	0.15
2004	n/a	0.13

Table 2.27–Definitions of symbols and terms used in the Pacific cod projection tables.

Symbol	Definition
SPR	Equilibrium spawning per recruit, expressed as a percentage of the maximum level
L90%CI	Lower bound of the 90% confidence interval
Median	Point that divides projection outputs into two groups of equal size (50% higher, 50% lower)
Mean	Average value of the projection outputs
U90%CI	Upper bound of the 90% confidence interval
St. Dev.	Standard deviation of the projection outputs

Table 2.28–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	760	0	0
40%	304	0.36	244
35%	266	0.43	262

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	295	295	295	295	0.00
2006	288	288	288	288	0.05
2007	269	270	270	271	0.68
2008	249	254	255	264	4.89
2009	235	251	254	283	15.69
2010	229	263	267	317	28.82
2011	231	279	283	352	38.65
2012	237	290	296	372	44.42
2013	241	295	304	382	47.56
2014	243	301	308	399	49.35
2015	246	303	310	404	50.00
2016	249	301	311	401	49.73
2017	248	303	312	402	49.08

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.35	0.35	0.35	0.35	0.000
2006	0.34	0.34	0.34	0.34	0.000
2007	0.32	0.32	0.32	0.32	0.001
2008	0.29	0.30	0.30	0.31	0.006
2009	0.27	0.29	0.30	0.33	0.019
2010	0.27	0.31	0.31	0.36	0.029
2011	0.27	0.33	0.33	0.36	0.031
2012	0.28	0.34	0.33	0.36	0.030
2013	0.28	0.35	0.34	0.36	0.028
2014	0.28	0.36	0.34	0.36	0.027
2015	0.29	0.36	0.34	0.36	0.026
2016	0.29	0.36	0.34	0.36	0.025
2017	0.29	0.36	0.34	0.36	0.025

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	227	227	227	227	0.00
2006	207	207	207	207	0.11
2007	176	178	179	183	2.20
2008	151	162	165	189	12.45
2009	136	167	173	232	30.91
2010	133	187	194	277	45.95
2011	139	210	214	297	51.68
2012	145	225	226	308	53.35
2013	150	232	233	319	53.67
2014	152	239	236	326	53.82
2015	157	239	238	326	52.94
2016	158	237	239	324	52.07
2017	158	238	239	326	51.42

Table 2.29–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that the ratio of F to $max\ F_{ABC}$ in 2005-2017 is fixed at a value of 0.90, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	760	0	0
40%	304	0.36	244
35%	266	0.43	262

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	296	296	296	296	0.00
2006	295	295	295	295	0.05
2007	279	280	280	281	0.68
2008	260	265	266	275	4.92
2009	245	262	265	294	15.88
2010	239	273	278	330	29.63
2011	241	289	295	368	40.59
2012	247	302	309	390	47.49
2013	251	309	318	404	51.43
2014	253	315	324	422	53.71
2015	257	319	327	430	54.67
2016	260	319	329	429	54.54
2017	261	321	330	428	53.91

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.31	0.31	0.31	0.31	0.000
2006	0.31	0.31	0.31	0.31	0.000
2007	0.30	0.30	0.30	0.30	0.001
2008	0.27	0.28	0.28	0.29	0.006
2009	0.26	0.28	0.28	0.31	0.017
2010	0.25	0.29	0.29	0.33	0.024
2011	0.25	0.31	0.30	0.33	0.025
2012	0.26	0.32	0.31	0.33	0.023
2013	0.26	0.33	0.31	0.33	0.022
2014	0.27	0.33	0.31	0.33	0.021
2015	0.27	0.33	0.31	0.33	0.019
2016	0.27	0.33	0.31	0.33	0.019
2017	0.28	0.33	0.31	0.33	0.018

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	206	206	206	206	0.00
2006	195	195	195	195	0.11
2007	170	172	172	176	2.05
2008	147	158	161	183	11.70
2009	133	163	168	224	28.64
2010	129	180	187	258	41.59
2011	135	202	204	278	46.60
2012	141	216	215	290	48.23
2013	144	223	222	300	48.73
2014	148	228	226	308	48.90
2015	152	228	228	308	48.20
2016	155	228	229	306	47.29
2017	155	229	230	310	46.56

Table 2.30–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that F = ½ $max\ F_{ABC}$ in 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	760	0	0
40%	304	0.36	244
35%	266	0.43	262

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	300	300	300	300	0.00
2006	325	325	325	325	0.05
2007	330	330	330	332	0.72
2008	321	326	327	337	5.26
2009	308	326	330	362	17.82
2010	299	339	345	409	35.68
2011	299	361	368	459	52.03
2012	303	380	389	497	63.50
2013	308	396	407	524	70.46
2014	314	412	420	546	74.43
2015	323	422	430	566	76.29
2016	329	429	437	572	76.56
2017	336	433	442	569	75.73

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.17	0.17	0.17	0.17	0.000
2006	0.18	0.18	0.18	0.18	0.000
2007	0.18	0.18	0.18	0.18	0.000
2008	0.18	0.18	0.18	0.18	0.000
2009	0.18	0.18	0.18	0.18	0.001
2010	0.17	0.18	0.18	0.18	0.003
2011	0.17	0.18	0.18	0.18	0.003
2012	0.18	0.18	0.18	0.18	0.003
2013	0.18	0.18	0.18	0.18	0.003
2014	0.18	0.18	0.18	0.18	0.003
2015	0.18	0.18	0.18	0.18	0.002
2016	0.18	0.18	0.18	0.18	0.002
2017	0.18	0.18	0.18	0.18	0.002

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	119	119	119	119	0.00
2006	125	125	125	125	0.04
2007	122	123	123	125	1.01
2008	117	123	124	135	5.64
2009	112	128	129	153	12.98
2010	108	135	137	171	20.12
2011	111	144	146	187	24.77
2012	115	150	153	199	27.44
2013	118	156	159	207	28.91
2014	121	160	162	215	29.63
2015	124	162	165	218	29.66
2016	127	164	167	217	29.33
2017	129	166	169	219	28.85

Table 2.31–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that F = the 1999-2003 average in 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	760	0	0
40%	304	0.36	244
35%	266	0.43	262

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	297	297	297	297	0.00
2006	304	304	304	304	0.05
2007	294	295	295	296	0.71
2008	275	280	281	291	5.22
2009	257	275	278	310	17.40
2010	245	284	289	349	33.92
2011	243	301	308	392	48.09
2012	246	317	324	421	57.18
2013	251	329	338	440	62.16
2014	255	340	347	459	64.72
2015	262	347	354	473	65.63
2016	267	352	358	471	65.28
2017	271	354	361	471	64.28

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.27	0.27	0.27	0.27	0.000
2006	0.27	0.27	0.27	0.27	0.000
2007	0.27	0.27	0.27	0.27	0.000
2008	0.27	0.27	0.27	0.27	0.000
2009	0.27	0.27	0.27	0.27	0.000
2010	0.27	0.27	0.27	0.27	0.000
2011	0.27	0.27	0.27	0.27	0.000
2012	0.27	0.27	0.27	0.27	0.000
2013	0.27	0.27	0.27	0.27	0.000
2014	0.27	0.27	0.27	0.27	0.000
2015	0.27	0.27	0.27	0.27	0.000
2016	0.27	0.27	0.27	0.27	0.000
2017	0.27	0.27	0.27	0.27	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	179	179	179	179	0.00
2006	174	174	174	174	0.06
2007	163	164	165	167	1.50
2008	152	160	162	177	8.33
2009	144	164	167	201	18.50
2010	141	174	178	225	27.39
2011	143	184	188	245	33.17
2012	146	192	196	258	36.35
2013	148	198	202	267	38.03
2014	151	202	206	276	38.76
2015	154	205	209	277	38.62
2016	157	205	211	277	38.08
2017	159	207	212	279	37.44

Table 2.32–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that *F* = 0 in 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	760	0	0
40%	304	0.36	244
35%	266	0.43	262

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	306	306	306	306	0.00
2006	368	368	368	368	0.05
2007	413	414	414	415	0.72
2008	439	445	446	456	5.33
2009	452	471	475	510	18.74
2010	461	507	513	586	39.95
2011	473	549	557	665	62.54
2012	486	585	597	737	81.48
2013	501	620	632	791	95.43
2014	513	648	662	834	104.98
2015	531	675	687	879	110.96
2016	544	695	708	907	114.45
2017	560	712	723	933	115.17

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0	0	0	0	0
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0	0	0	0	0
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0

Table 2.33–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = F_{OFL}$ in 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	760	0	0
40%	304	0.36	244
35%	266	0.43	262

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	292	292	292	292	0.00
2006	276	276	276	276	0.05
2007	252	252	253	254	0.67
2008	231	235	236	246	4.85
2009	217	233	236	264	15.38
2010	213	245	249	297	27.58
2011	216	261	265	325	35.61
2012	221	271	275	343	39.45
2013	225	274	281	349	41.13
2014	226	278	283	360	42.00
2015	229	277	284	363	42.12
2016	230	278	284	358	41.56
2017	229	277	284	359	40.85

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.42	0.42	0.42	0.42	0.000
2006	0.39	0.39	0.39	0.39	0.000
2007	0.36	0.36	0.36	0.36	0.001
2008	0.32	0.33	0.33	0.35	0.007
2009	0.30	0.33	0.33	0.37	0.023
2010	0.30	0.35	0.35	0.42	0.038
2011	0.30	0.37	0.37	0.43	0.042
2012	0.31	0.38	0.38	0.43	0.042
2013	0.31	0.39	0.39	0.43	0.041
2014	0.32	0.40	0.39	0.43	0.040
2015	0.32	0.39	0.39	0.43	0.039
2016	0.32	0.39	0.39	0.43	0.038
2017	0.32	0.39	0.39	0.43	0.038

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	265	265	265	265	0.00
2006	226	226	226	226	0.13
2007	185	187	188	192	2.46
2008	156	169	172	198	13.76
2009	141	175	182	246	34.47
2010	139	197	207	303	52.87
2011	146	222	229	334	60.43
2012	153	237	243	342	62.46
2013	158	242	249	356	62.78
2014	159	248	251	358	62.66
2015	163	246	252	356	61.57
2016	163	245	252	356	60.85
2017	165	244	252	356	60.35

Table 2.34–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in each year 2005-2006 and $F = F_{OFL}$ thereafter, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	760	0	0
40%	304	0.36	244
35%	266	0.43	262

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	295	295	295	295	0.00
2006	288	288	288	288	0.05
2007	267	268	268	269	0.67
2008	239	244	245	254	4.83
2009	221	237	240	268	15.30
2010	214	247	250	297	27.44
2011	216	261	265	325	35.50
2012	221	270	275	343	39.40
2013	225	274	280	349	41.10
2014	226	278	283	360	41.98
2015	229	277	284	362	42.11
2016	230	278	284	358	41.55
2017	229	277	284	359	40.85

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.35	0.35	0.35	0.35	0.000
2006	0.34	0.34	0.34	0.34	0.000
2007	0.38	0.38	0.38	0.38	0.001
2008	0.34	0.34	0.34	0.36	0.007
2009	0.31	0.33	0.34	0.38	0.023
2010	0.30	0.35	0.35	0.42	0.037
2011	0.30	0.37	0.37	0.43	0.042
2012	0.31	0.38	0.38	0.43	0.042
2013	0.31	0.39	0.39	0.43	0.041
2014	0.32	0.39	0.39	0.43	0.040
2015	0.32	0.39	0.39	0.43	0.039
2016	0.32	0.39	0.39	0.43	0.038
2017	0.32	0.39	0.39	0.43	0.038

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	227	227	227	227	0.00
2006	207	207	207	207	0.11
2007	206	209	209	214	2.61
2008	165	179	182	209	14.16
2009	145	180	186	251	34.68
2010	140	199	208	305	52.70
2011	147	222	230	334	60.28
2012	153	237	242	342	62.43
2013	158	242	249	355	62.80
2014	159	247	251	358	62.67
2015	163	246	252	356	61.58
2016	163	245	252	356	60.85
2017	165	244	252	356	60.35

Table 2.35–Correlations ("Corr.") between age 1 year class strength ("Nos.", expressed as millions of age 1 fish spawned in "Year") and monthly Pacific Decadal Oscillation indices.

Year	Nos.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1977	1176	1.65	1.11	0.72	0.3	0.31	0.42	0.19	0.64	-0.55	-0.61	-0.72	-0.69
1978	615	0.34	1.45	1.34	1.29	0.90	0.15	-1.24	-0.56	-0.44	0.10	-0.07	-0.43
1979	906	-0.58	-1.33	0.30	0.89	1.09	0.17	0.84	0.52	1.00	1.06	0.48	-0.42
1980	214	-0.11	1.32	1.09	1.49	1.20	-0.22	0.23	0.51	0.10	1.35	0.37	-0.10
1981	829	0.59	1.46	0.99	1.45	1.75	1.69	0.84	0.18	0.42	0.18	0.80	0.67
1982	964	0.34	0.20	0.19	-0.19	-0.58	-0.78	0.58	0.39	0.84	0.37	-0.25	0.26
1983	566	0.56	1.14	2.11	1.87	1.80	2.36	3.51	1.85	0.91	0.96	1.02	1.69
1984	933	1.50	1.21	1.77	1.52	1.30	0.18	-0.18	-0.03	0.67	0.58	0.71	0.82
1985	397	1.27	0.94	0.57	0.19	0.00	0.18	1.07	0.81	0.44	0.29	-0.75	0.38
1986	256	1.12	1.61	2.18	1.55	1.16	0.89	1.38	0.22	0.22	1.00	1.77	1.77
1987	223	1.88	1.75	2.10	2.16	1.85	0.73	2.01	2.83	2.44	1.36	1.47	1.27
1988	604	0.93	1.24	1.42	0.94	1.20	0.74	0.64	0.19	-0.37	-0.10	-0.02	-0.43
1989	793	-0.95	-1.02	-0.83	-0.32	0.47	0.36	0.83	0.09	0.05	-0.12	-0.50	-0.21
1990	453	-0.30	-0.65	-0.62	0.27	0.44	0.44	0.27	0.11	0.38	-0.69	-1.69	-2.23
1991	596	-2.02	-1.19	-0.74	-1.01	-0.51	-1.47	-0.10	0.36	0.65	0.49	0.42	0.09
1992	606	0.05	0.31	0.67	0.75	1.54	1.26	1.90	1.44	0.83	0.93	0.93	0.53
1993	235	0.05	0.19	0.76	1.21	2.13	2.34	2.35	2.69	1.56	1.41	1.24	1.07
1994	285	1.21	0.59	0.80	1.05	1.23	0.46	0.06	-0.79	-1.36	-1.32	-1.96	-1.79
1995	479	-0.49	0.46	0.75	0.83	1.46	1.27	1.71	0.21	1.16	0.47	-0.28	0.16
1996	576	0.59	0.75	1.01	1.46	2.18	1.10	0.77	-0.14	0.24	-0.33	0.09	-0.03
1997	360	0.23	0.28	0.65	1.05	1.83	2.76	2.35	2.79	2.19	1.61	1.12	0.67
1998	463	0.83	1.56	2.01	1.27	0.70	0.40	-0.04	-0.22	-1.21	-1.39	-0.52	-0.44
1999	752	-0.32	-0.66	-0.33	-0.41	-0.68	-1.30	-0.66	-0.96	-1.53	-2.23	-2.05	-1.63
2000	471	-2.00	-0.83	0.29	0.35	-0.05	-0.44	-0.66	-1.19	-1.24	-1.30	-0.53	0.52
2001	357	0.60	0.29	0.45	-0.31	-0.30	-0.47	-1.31	-0.77	-1.37	-1.37	-1.26	-0.93
2002	260	0.27	-0.64	-0.43	-0.32	-0.63	-0.35	-0.31	0.60	0.43	0.42	1.51	2.10
2003	377	2.09	1.75	1.51	1.18	0.89	0.68	0.96	0.88	0.01	0.83	0.52	0.33
Corr:		-0.06	-0.17	-0.19	-0.24	-0.19	-0.20	-0.17	-0.25	-0.11	-0.20	-0.20	-0.22

Table 2.36a–Bycatch of nontarget and "other" species taken in the EBS Pacific cod trawl fishery. The first part of the table ("Bycatch in...") shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the EBS Pacific cod trawl fishery, broken down by year. The second part of the table ("Proportion of...") shows the same quantity expressed relative to the total EBS catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the EBS during that year.

	Bycatch in EBS Pacific cod trawl fishery						Proportion of total EBS catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	1508	1365	893	1280	749	925	0.22	0.26	0.20	0.23	0.12	0.12
skates	678	676	946	981	583	1303	0.04	0.04	0.07	0.06	0.03	0.05
shark	0	0	0	9	2	3	0.00	0.00	0.00	0.15	0.09	0.08
salmonshk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
dogfish	0	0	0	0	0	1	0.00	0.00	0.00	0.00	0.04	0.08
sleepershk	8	33	4	0	12	10	0.03	0.10	0.01	0.00	0.02	0.01
octopus	29	19	17	68	17	30	0.14	0.13	0.13	0.19	0.09	0.08
squid	7	1	0	2	4	1	0.00	0.00	0.00	0.00	0.00	0.00
smelts	1	0	1	0	0	0	0.03	0.00	0.03	0.00	0.00	0.00
gunnel	0	0	0	0	0	0		0.00	0.00	0.00	0.71	0.00
sticheidae	0	0	0	0	0	0	0.00	0.03	0.00	0.00	0.01	0.00
sandfish	0	0	3	0	0	1	0.27	0.08	0.91	0.02	0.05	0.36
lanternfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
sandlance	0	0	0	0	0	0	0.00		0.00	0.00	0.90	0.01
grenadier	1	6	0	3	0	0	0.00	0.00	0.00	0.00	0.00	0.00
otherfish	231	232	195	302	220	157	0.16	0.21	0.20	0.24	0.18	0.14
crabs	10	6	5	8	3	6	0.03	0.03	0.05	0.06	0.02	0.04
starfish	133	63	83	109	57	98	0.02	0.02	0.03	0.03	0.01	0.02
jellyfish	948	213	416	413	112	93	0.11	0.03	0.06	0.04	0.03	0.05
invertunid	1	9	3	11	1	51	0.00	0.02	0.02	0.01	0.00	0.05
seapen/whip	0	0	0	0	0	0	0.10	0.09	0.01	0.06	0.00	0.00
sponge	73	34	39	28	9	13	0.23	0.09	0.22	0.30	0.05	0.08
anemone	14	5	18	10	6	9	0.08	0.05	0.11	0.03	0.03	0.03
tunicate	6	10	0	67	5	1	0.00	0.01	0.00	0.06	0.00	0.00
benthinv	25	18	11	23	6	12	0.04	0.03	0.05	0.06	0.01	0.03
snails	0	0	0	0	0	0					0.00	0.00
echinoderm	13	4	13	13	20	14	0.31	0.20	0.54	0.33	0.50	0.46
coral	0	0	0	4	0	0	0.02	0.01	0.04	0.37	0.00	0.00
shrimp	0	0	0	0	0	0	0.07	0.03	0.01	0.00	0.01	0.00
birds	0	0	0	0	0	0	0.00	0.01	0.00	0.00	0.00	0.00

Table 2.36b–Bycatch of nontarget and "other" species taken in the EBS Pacific cod longline fishery. The first part of the table ("Bycatch in...") shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the EBS Pacific cod longline fishery, broken down by year. The second part of the table ("Proportion of...") shows the same quantity expressed relative to the total EBS catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the EBS during that year.

	Bycatch in EBS Pacific cod longline fishery						Proportion of total EBS catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	706	931	821	801	1142	1383	0.11	0.18	0.18	0.14	0.19	0.18
skates	12961	12808	9178	11578	11932	17507	0.77	0.70	0.69	0.68	0.66	0.66
shark	27	48	18	47	17	22	0.50	0.40	0.11	0.78	0.70	0.48
salmonshk	0	1	1	0	1	10	0.00	0.05	0.04	0.01	0.05	0.22
dogfish	4	5	5	8	11	8	1.00	0.90	0.99	0.98	0.83	0.92
sleepershk	67	114	99	114	240	250	0.24	0.34	0.35	0.33	0.37	0.30
octopus	15	15	13	29	15	76	0.07	0.10	0.10	0.08	0.08	0.19
squid	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
smelts	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
gunnel	0	0	0	0	0	0		0.60	0.00	0.80	0.00	0.00
sticheidae	0	0	0	0	0	0	0.01	0.00	0.00	0.00	0.00	0.56
sandfish	0	0	0	0	0	0	0.00	0.00	0.01	0.00	0.00	0.00
lanternfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
sandlance	0	0	0	0	0	0	0.00		0.00	0.00	0.00	0.00
grenadier	437	604	356	364	162	336	0.15	0.12	0.08	0.09	0.07	0.06
otherfish	43	27	38	38	71	122	0.03	0.03	0.04	0.03	0.06	0.11
crabs	1	0	0	1	1	3	0.00	0.00	0.00	0.00	0.01	0.01
starfish	136	141	250	132	319	384	0.02	0.04	0.08	0.04	0.08	0.08
jellyfish	5	7	24	2	2	5	0.00	0.00	0.00	0.00	0.00	0.00
invertunid	10	12	1	6	10	11	0.01	0.02	0.01	0.01	0.01	0.01
seapen/whip	2	2	4	3	6	41	0.83	0.79	0.87	0.63	0.79	0.95
sponge	1	1	2	1	0	5	0.00	0.00	0.01	0.01	0.00	0.03
anemone	76	58	123	200	115	195	0.42	0.51	0.73	0.58	0.55	0.59
tunicate	1	1	0	2	0	1	0.00	0.00	0.00	0.00	0.00	0.00
benthinv	7	5	10	11	12	12	0.01	0.01	0.04	0.03	0.02	0.03
snails	0	0	0	0	0	0					1.00	0.00
echinoderm	1	0	3	0	0	0	0.02	0.00	0.11	0.00	0.00	0.01
coral	1	0	0	3	1	2	0.07	0.02	0.04	0.30	0.01	0.03
shrimp	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
birds	26	33	17	24	13	13	0.98	0.86	0.81	0.97	0.88	0.96

Table 2.36c–Bycatch of nontarget and “other” species taken in the EBS Pacific cod pot fishery. The first part of the table (“Bycatch in...”) shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the EBS Pacific cod pot fishery, broken down by year. The second part of the table (“Proportion of...”) shows the same quantity expressed relative to the total EBS catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the EBS during that year.

	Bycatch in EBS Pacific cod pot fishery						Proportion of total EBS catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	351	267	438	494	315	384	0.05	0.05	0.10	0.09	0.05	0.05
skates	1	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
shark	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
salmonshk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
dogfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
sleepershk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
octopus	79	95	80	199	140	254	0.38	0.65	0.64	0.56	0.75	0.65
squid	0	0	0	0	1	0	0.00	0.00	0.00	0.00	0.00	0.00
smelts	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
gunnel	0	0	0	0	0	0		0.00	0.00	0.00	0.00	0.00
sticheidae	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
sandfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
lanternfish	0	0	0	0	0	0	0.02	0.00	0.00	0.00	0.00	0.00
sandlance	0	0	0	0	0	0	0.00		0.00	0.00	0.00	0.00
grenadier	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
otherfish	27	44	32	12	48	23	0.02	0.04	0.03	0.01	0.04	0.02
crabs	1	1	4	2	1	2	0.00	0.00	0.04	0.01	0.01	0.01
starfish	64	14	15	35	31	11	0.01	0.00	0.01	0.01	0.01	0.00
jellyfish	11	1	16	0	6	2	0.00	0.00	0.00	0.00	0.00	0.00
invertunid	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
seapen/whip	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
sponge	0	0	0	0	0	1	0.00	0.00	0.00	0.00	0.00	0.00
anemone	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
tunicate	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
benthinv	8	3	4	11	4	9	0.01	0.01	0.02	0.03	0.01	0.02
snails	0	0	0	0	0	0					0.00	0.00
echinoderm	1	0	0	2	1	0	0.02	0.02	0.02	0.04	0.02	0.01
coral	0	0	0	0	0	0	0.02	0.00	0.00	0.00	0.00	0.00
shrimp	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
birds	0	0	0	0	0	0	0.00	0.00	0.01	0.00	0.00	0.00

Table 2.36d–Bycatch of nontarget and “other” species taken in the AI Pacific cod trawl fishery. The first part of the table (“Bycatch in...”) shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the AI Pacific cod trawl fishery, broken down by year. The second part of the table (“Proportion of...”) shows the same quantity expressed relative to the total AI catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the AI during that year.

	Bycatch in AI Pacific cod trawl fishery						Proportion of total AI catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	107	146	131	257	102	131	0.14	0.14	0.14	0.18	0.06	0.12
skates	37	95	38	72	49	97	0.04	0.08	0.05	0.04	0.02	0.14
shark	0	0	0	0	0	0	0.00	0.00	0.00	0.03	0.00	0.00
salmonshk	0	0	0	4	0	0	0.00	0.00	0.00	1.00	0.00	
dogfish	0	0	0	0	0	0	0.04	0.00	0.00	0.00	0.00	0.00
sleepershk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.01
octopus	2	2	9	2	1	9	0.06	0.05	0.04	0.03	0.03	0.38
squid	1	0	0	1	2	4	0.01	0.01	0.01	0.07	0.30	0.25
smelts	0	0	0	0	0	0	0.00	0.95	0.00	1.00	1.00	0.00
gunnel	0	0	0	0	0	0			1.00		1.00	
sticheidae	0	0	0	0	0	0	0.00			0.00		
sandfish	0	0	0	0	0	0	0.00			0.00		
lanternfish	0	0	0	0	0	0	0.00	0.00				
sandlance	0	0	0	0	0	0					0.00	0.00
grenadier	0	0	0	0	0	9	0.00	0.00	0.00	0.00	0.00	0.00
otherfish	6	38	29	25	26	15	0.04	0.14	0.09	0.12	0.11	0.07
crabs	1	1	0	0	1	2	0.13	0.44	0.27	0.22	0.42	0.88
starfish	2	3	5	5	5	5	0.12	0.15	0.29	0.20	0.17	0.46
jellyfish	0	0	0	0	0	0	0.01	0.17	0.00	0.99	0.01	0.44
invertunid	0	2	3	6	2	0	0.00	0.03	0.34	0.40	0.36	0.02
seapen/whip	0	0	0	0	0	0	0.85	0.23	0.54	0.33	0.08	0.16
sponge	4	52	15	15	13	28	0.02	0.47	0.10	0.21	0.18	0.16
anemone	0	0	1	0	0	0	0.09	0.08	0.41	0.17	0.05	0.17
tunicate	0	0	0	0	1	0	0.63	0.75	0.08	0.58	0.40	0.07
benthinv	4	3	1	2	3	6	0.90	0.68	0.16	0.73	0.76	0.92
snails	0	0	0	0	0	0						
echinoderm	0	1	1	1	1	2	0.16	0.26	0.23	0.35	0.44	0.75
coral	2	8	2	8	3	11	0.07	0.48	0.03	0.24	0.15	0.52
shrimp	0	0	0	0	0	0	0.01	0.05	0.00	0.11	0.19	0.10
birds	0	1	0	0	0	0	0.02	0.11	0.02	0.04	0.01	0.16

Table 2.36e–Bycatch of nontarget and “other” species taken in the AI Pacific cod longline fishery. The first part of the table (“Bycatch in...”) shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the AI Pacific cod longline fishery, broken down by year. The second part of the table (“Proportion of...”) shows the same quantity expressed relative to the total AI catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the AI during that year.

	Bycatch in AI Pacific cod longline fishery						Proportion of total AI catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	334	597	356	662	1004	214	0.43	0.55	0.37	0.47	0.63	0.19
skates	338	727	473	1397	2184	246	0.39	0.64	0.59	0.77	0.87	0.35
shark	0	1	0	0	0	0	0.78	0.04	0.05	0.03	0.00	0.00
salmonshk	0	0	0	0	0	0	0.00	0.02	0.00	0.00	0.00	
dogfish	0	0	0	0	1	0	0.96	0.55	0.84	0.85	0.31	0.54
sleepershk	0	0	1	0	1	2	0.00	0.00	0.02	0.00	0.03	0.49
octopus	10	21	9	13	21	8	0.27	0.47	0.05	0.20	0.51	0.32
squid	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
smelts	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
gunnel	0	0	0	0	0	0			0.00		0.00	
sticheidae	0	0	0	0	0	0	0.00			0.00		
sandfish	0	0	0	0	0	0	0.00			0.00		
lanternfish	0	0	0	0	0	0	0.00	0.00				
sandlance	0	0	0	0	0	0					0.00	0.00
grenadier	397	83	215	151	6	88	0.14	0.05	0.07	0.05	0.00	0.03
otherfish	2	5	2	6	10	3	0.02	0.02	0.01	0.03	0.04	0.01
crabs	0	0	0	0	0	0	0.00	0.01	0.01	0.01	0.04	0.00
starfish	3	7	4	13	16	3	0.22	0.41	0.28	0.51	0.59	0.25
jellyfish	0	0	0	0	0	0	0.00	0.00	0.00	0.01	0.00	0.00
invertunid	0	1	0	1	0	0	0.00	0.01	0.02	0.06	0.08	0.02
seapen/whip	0	0	0	0	0	0	0.00	0.21	0.44	0.54	0.92	0.56
sponge	0	4	3	11	4	1	0.00	0.04	0.02	0.15	0.06	0.00
anemone	0	0	1	1	0	1	0.34	0.57	0.32	0.59	0.47	0.69
tunicate	0	0	0	0	0	0	0.01	0.00	0.00	0.24	0.00	0.00
benthinv	0	0	0	0	0	0	0.02	0.00	0.02	0.06	0.04	0.03
snails	0	0	0	0	0	0						
echinoderm	0	0	0	0	0	0	0.10	0.04	0.00	0.09	0.04	0.02
coral	0	1	2	6	3	1	0.02	0.03	0.04	0.17	0.16	0.03
shrimp	0	0	0	0	0	0	0.09	0.00	0.00	0.01	0.00	0.00
birds	2	2	2	2	1	0	0.75	0.45	0.55	0.66	0.48	0.16

Table 2.36f–Bycatch of nontarget and “other” species taken in the AI Pacific cod pot fishery. The first part of the table (“Bycatch in...”) shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the AI Pacific cod pot fishery, broken down by year. The second part of the table (“Proportion of...”) shows the same quantity expressed relative to the total AI catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the AI during that year.

	Bycatch in AI Pacific cod pot fishery						Proportion of total AI catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	7	12	221	211	42	0	0.01	0.01	0.23	0.15	0.03	0.00
skates	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
shark	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
salmonshk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	
dogfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
sleepershk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
octopus	24	18	182	47	17	0	0.62	0.40	0.90	0.75	0.41	0.00
squid	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
smelts	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
gunnel	0	0	0	0	0	0			0.00		0.00	
sticheidae	0	0	0	0	0	0	0.00			0.00		
sandfish	0	0	0	0	0	0	0.00			0.00		
lanternfish	0	0	0	0	0	0	0.00	0.00				
sandlance	0	0	0	0	0	0					0.00	0.00
grenadier	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
otherfish	0	0	7	1	4	0	0.00	0.00	0.02	0.01	0.02	0.00
crabs	0	0	1	1	0	0	0.00	0.06	0.51	0.61	0.31	0.00
starfish	0	0	1	1	0	0	0.00	0.00	0.05	0.05	0.00	0.00
jellyfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
invertunid	0	0	0	0	0	0	0.00	0.00	0.01	0.00	0.00	0.00
seapen/whip	0	0	0	0	0	0	0.00	0.00	0.00	0.07	0.00	0.00
sponge	0	0	0	4	0	0	0.00	0.00	0.00	0.06	0.00	0.00
anemone	0	0	0	0	0	0	0.00	0.01	0.00	0.00	0.00	0.00
tunicate	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
benthinv	0	0	1	0	0	0	0.00	0.01	0.09	0.12	0.00	0.00
snails	0	0	0	0	0	0						
echinoderm	0	0	1	1	0	0	0.01	0.00	0.20	0.18	0.00	0.00
coral	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
shrimp	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
birds	0	0	0	0	0	0	0.00	0.00	0.02	0.00	0.00	0.00

Table 2.37--Summary of major results for the stock assessment of Pacific cod in the BSAI region.

Tier	3a
Reference mortality rates	
M	0.37
$F_{40\%}$	0.36
$F_{35\%}$	0.43
Equilibrium spawning biomass	
$B_{35\%}$	266,000 t
$B_{40\%}$	304,000 t
$B_{100\%}$	760,000 t
Projected biomass for 2005	
Spawning (at *max* F_{ABC})	295,000 t
Age 3+	1,290,000 t
ABC for 2005	
F_{ABC} (maximum permissible)	0.35
F_{ABC} (recommended)	0.31
ABC (maximum permissible)	227,000 t
ABC (recommended)	206,000 t
Overfishing level for 2005	
Fishing Mortality	0.42
Catch	265,000 t

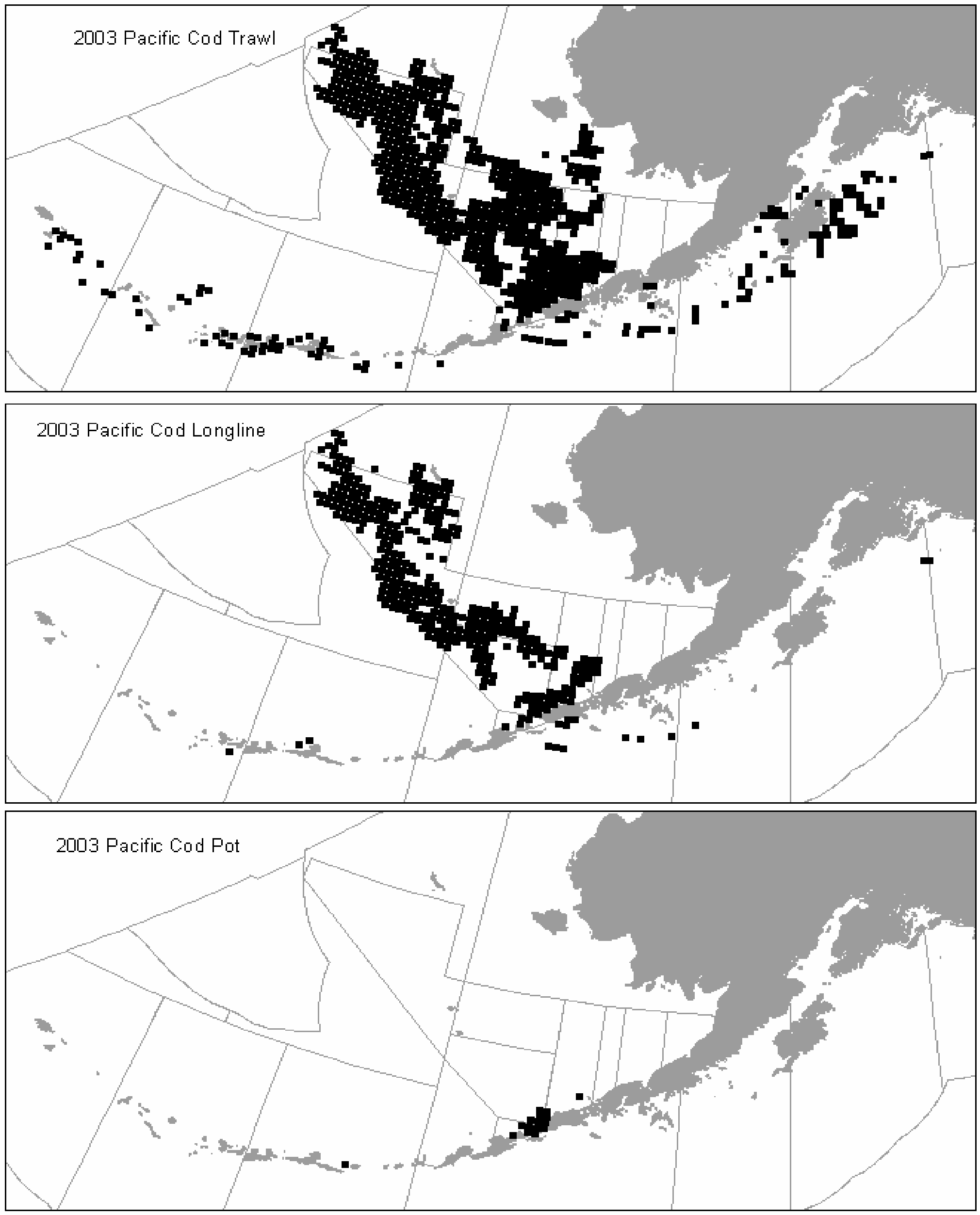


Figure 2.1. Maps showing each 20 km × 20 km square with at least 3 observed hauls/sets containing Pacific cod in 2003, by gear type.

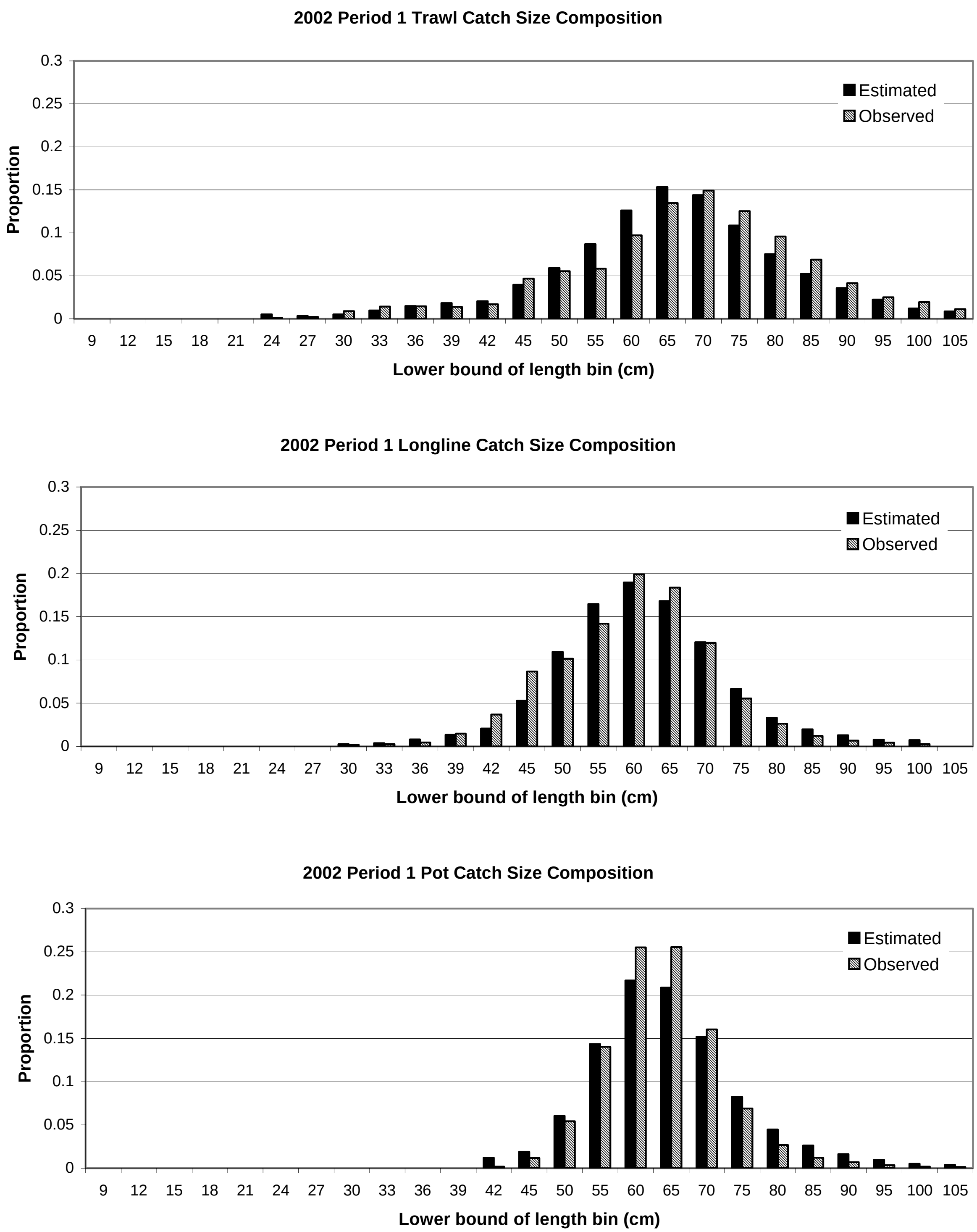


Figure 2.2–Estimated and observed size compositions from the 2002 period 1 fisheries.

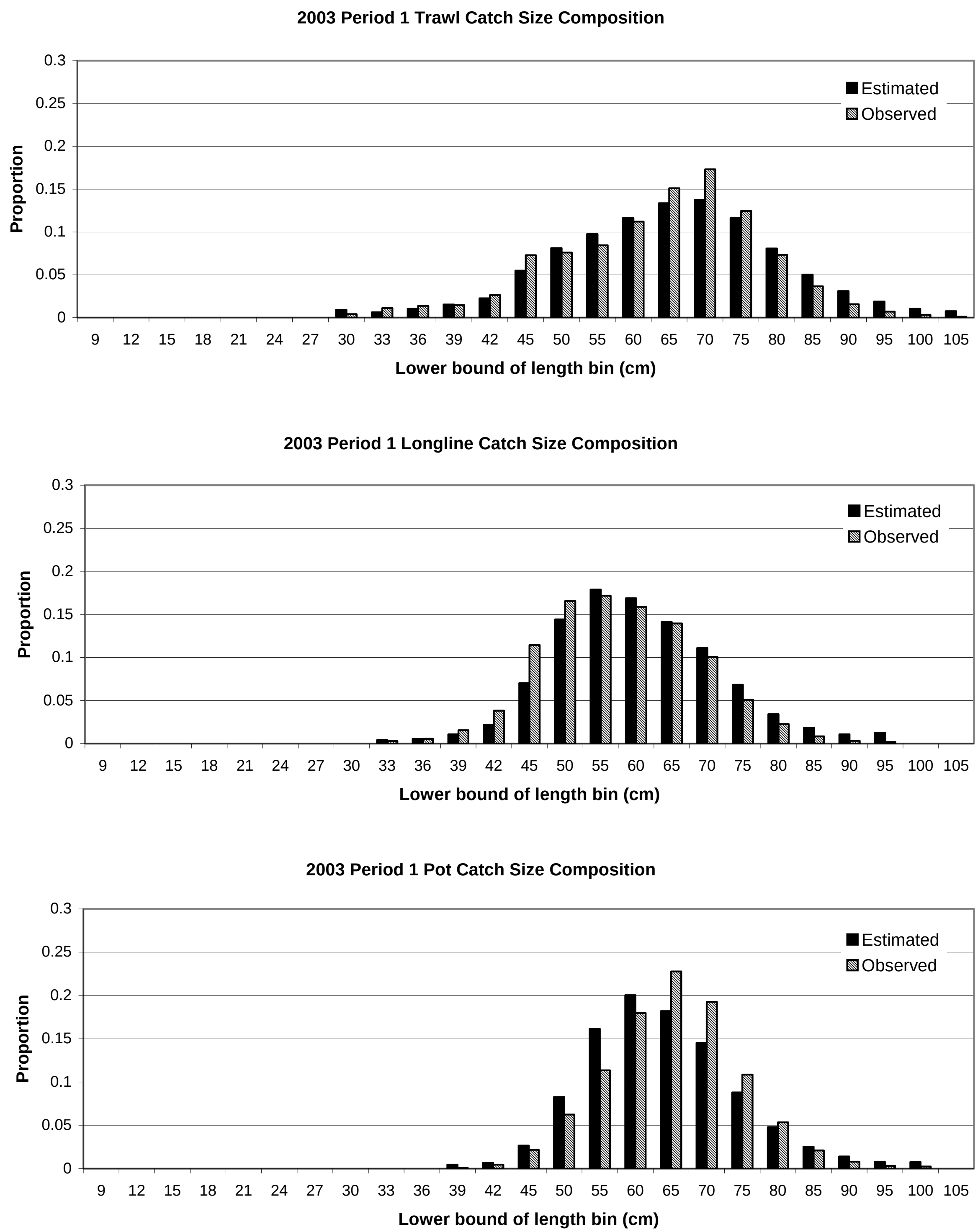
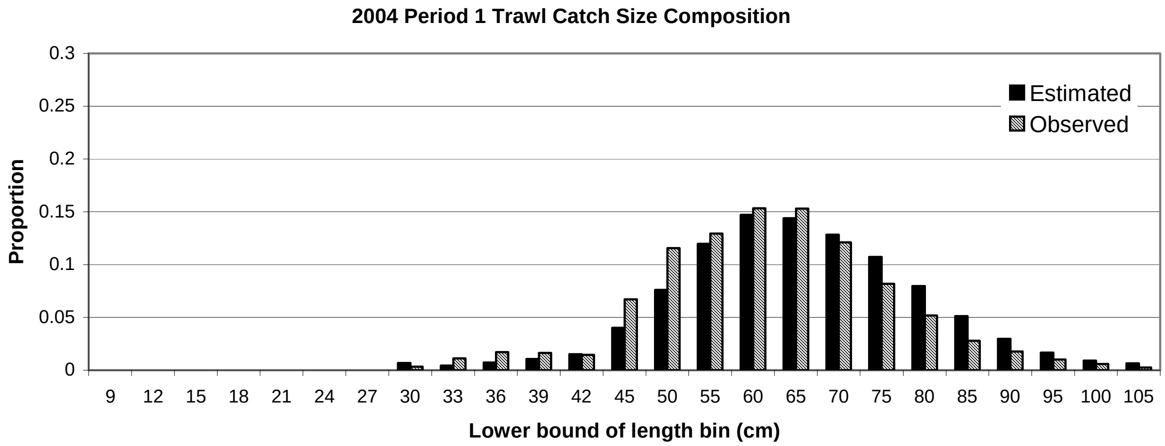
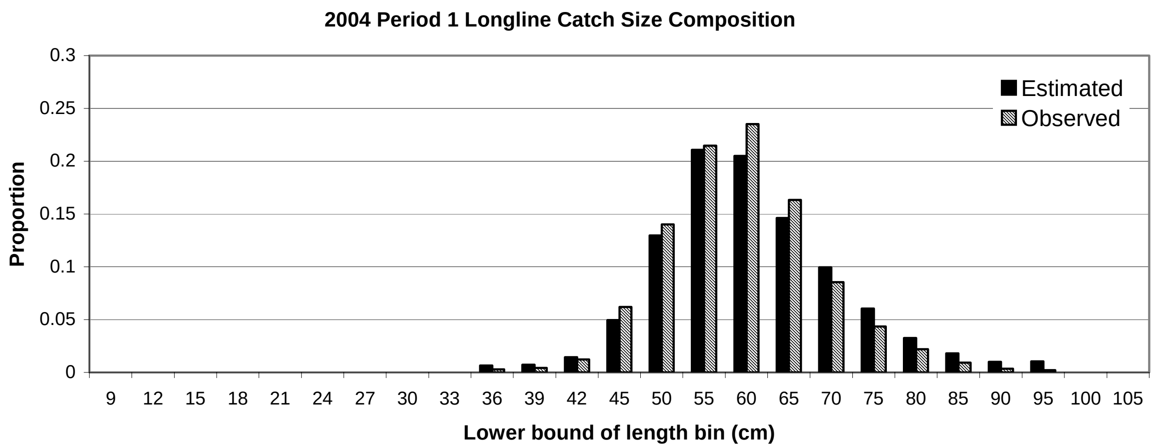


Figure 2.3–Estimated and observed size compositions from the 2003 period 1 fisheries.





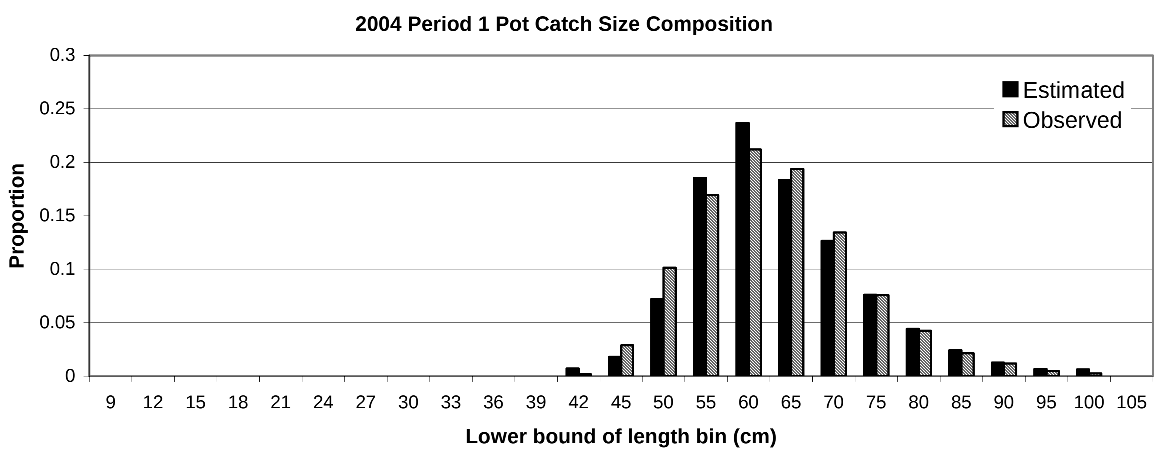
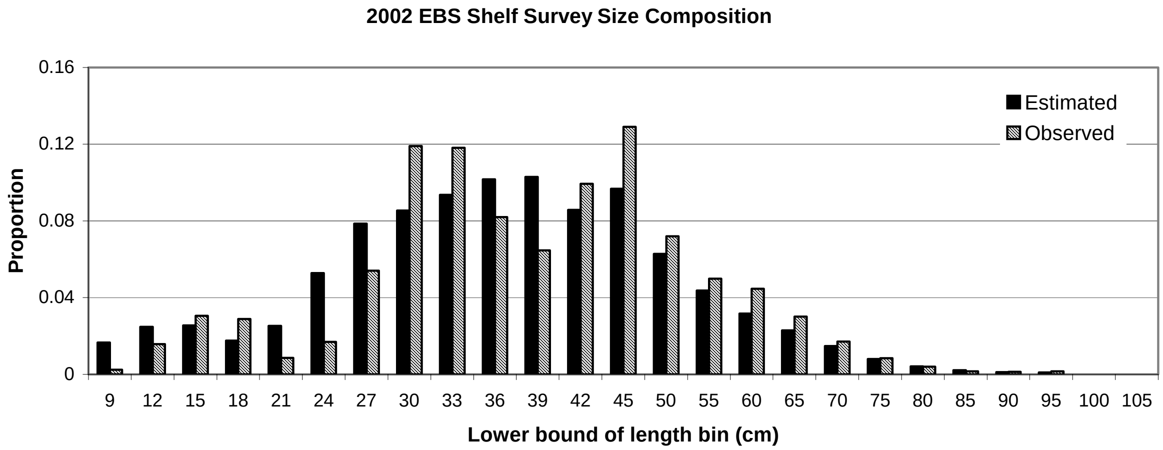
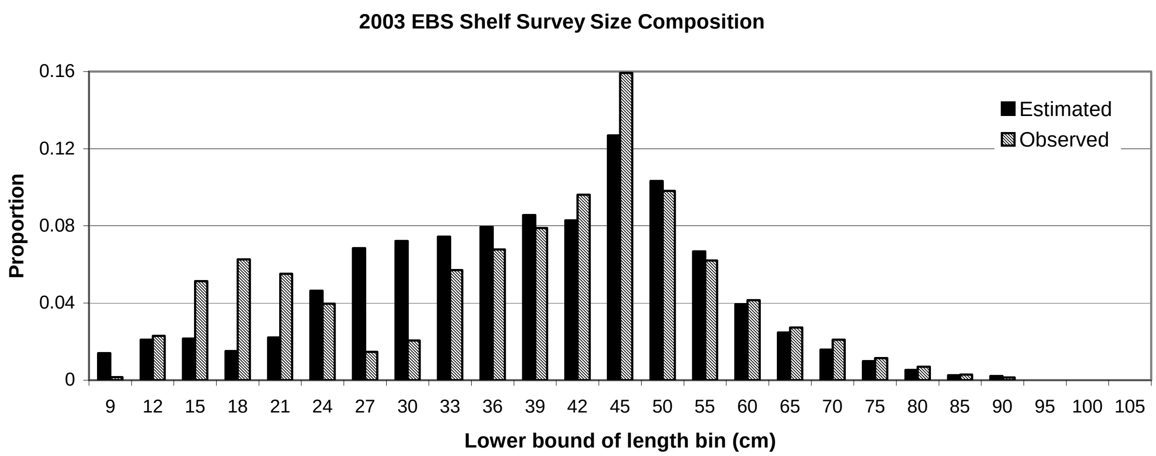


Figure 2.4–Estimated and observed size compositions from the 2004 period 1 fisheries.





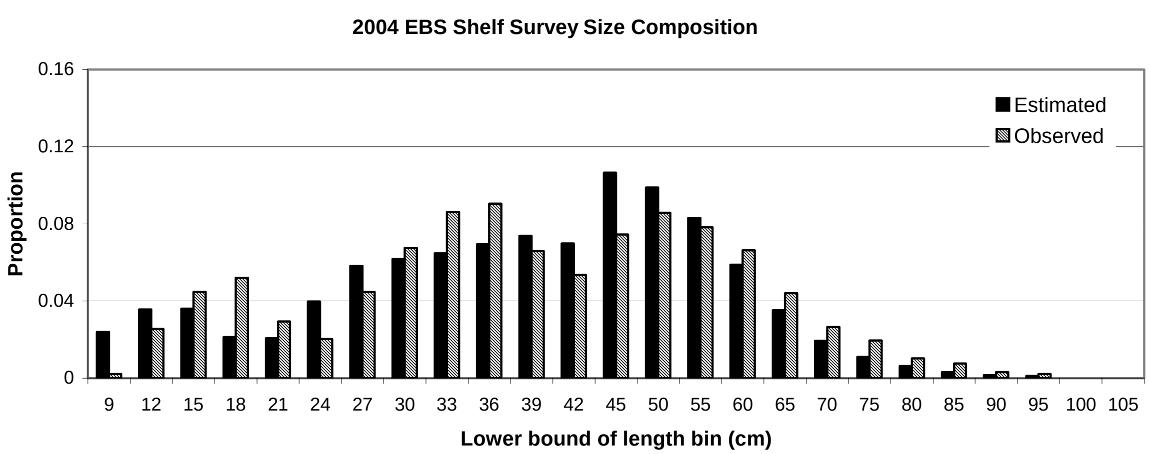
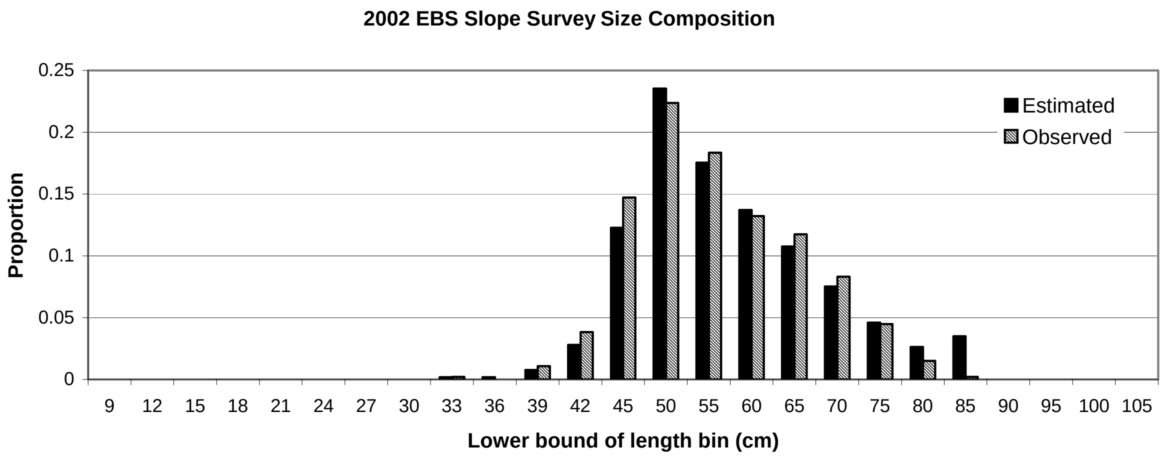


Figure 2.5a–Estimated and observed size compositions from the 3 most recent shelf surveys.



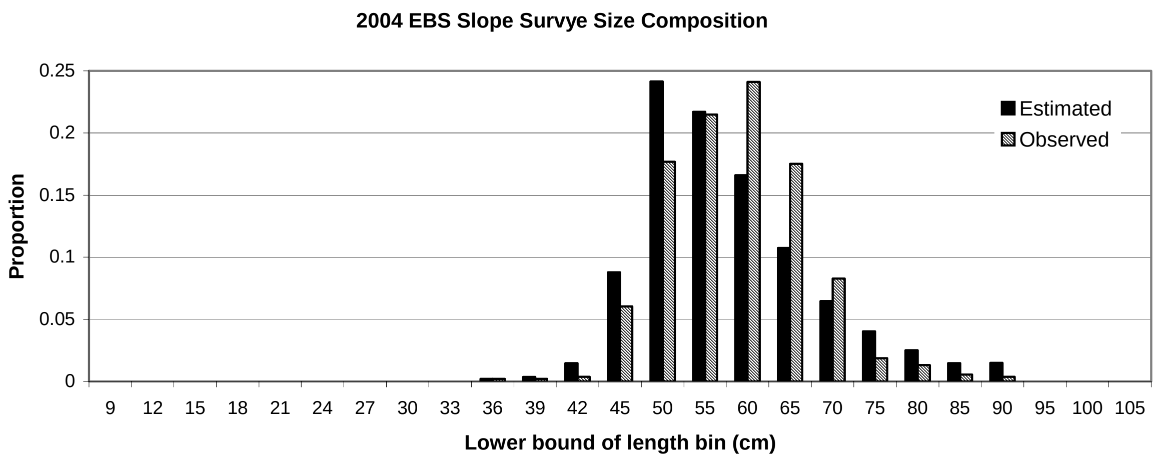


Figure 2.5b–Estimated and observed size compositions from the two slope surveys.

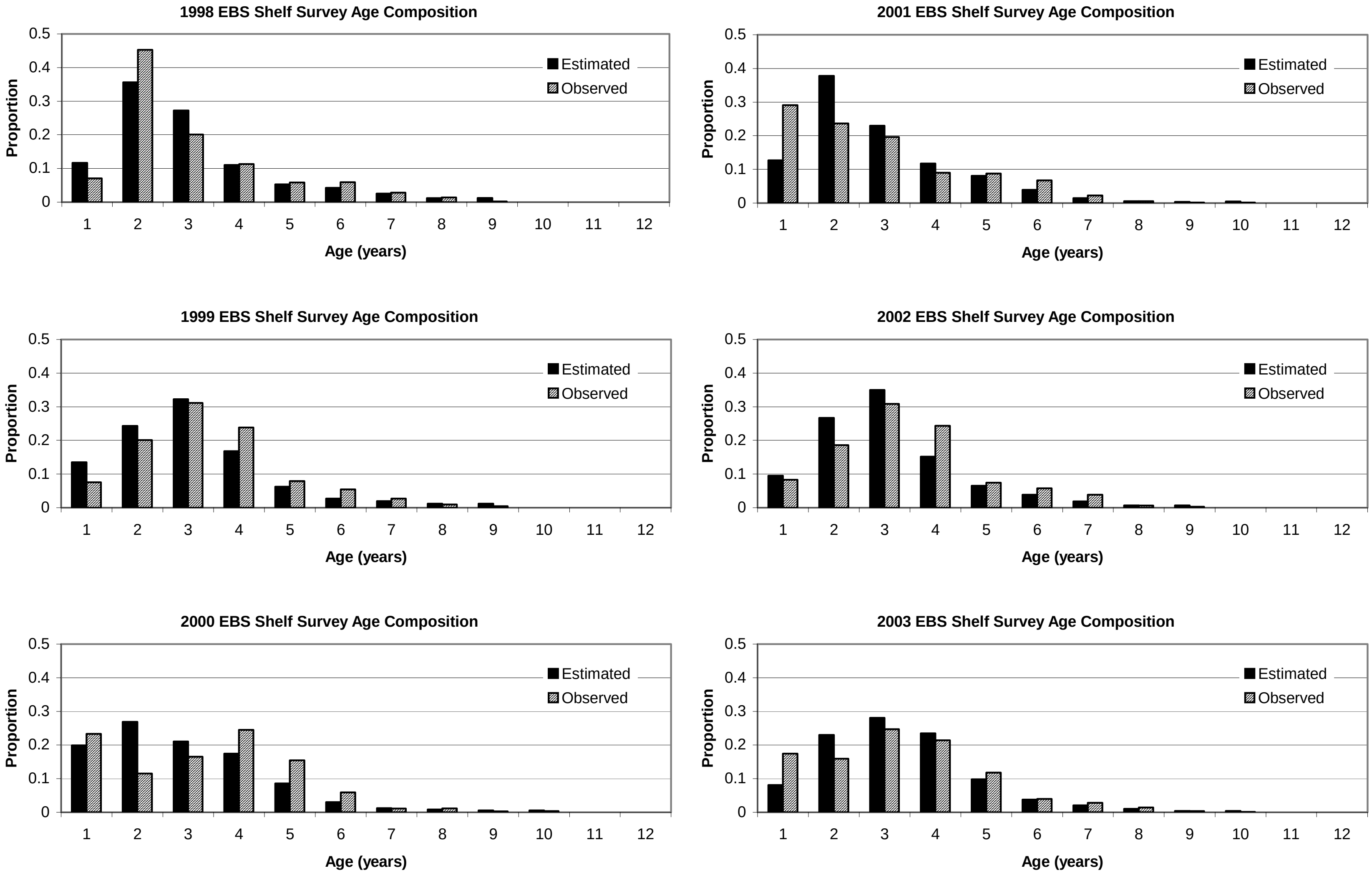


Figure 2.5c–Estimated and observed age compositions from the 1998-2003 shelf surveys.

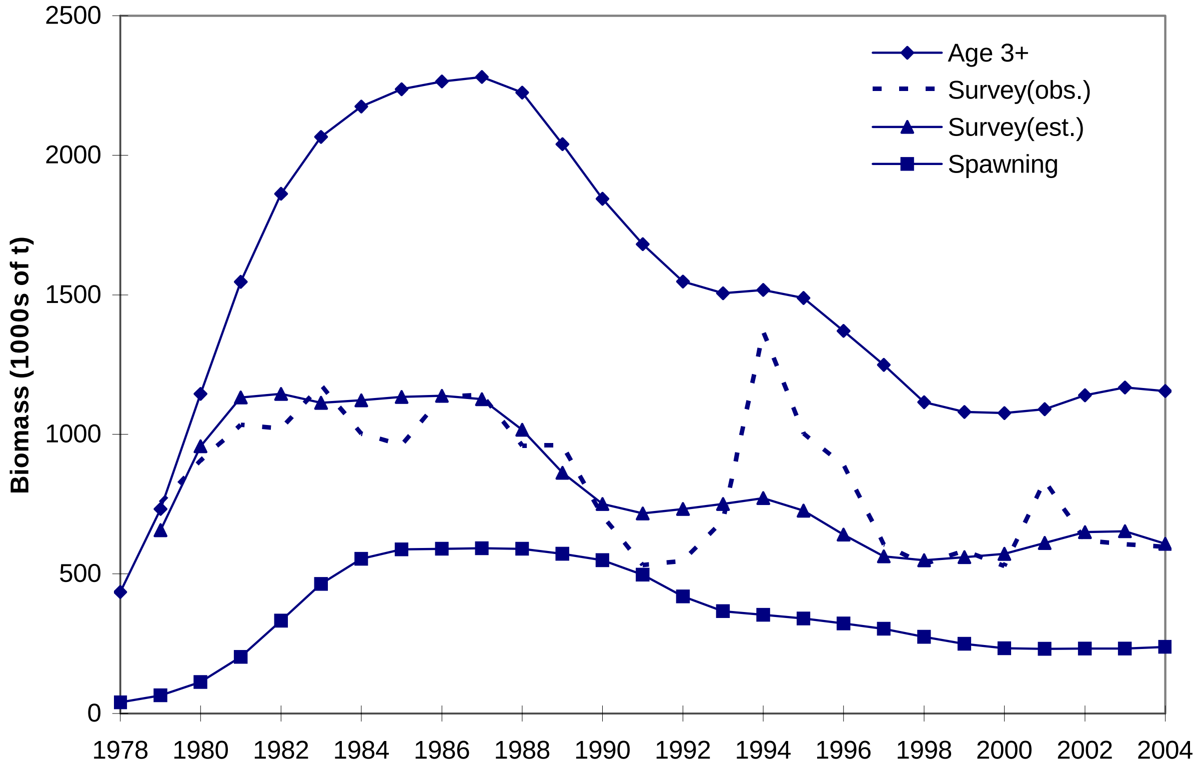


Figure 2.6–Time series of biomass estimates.

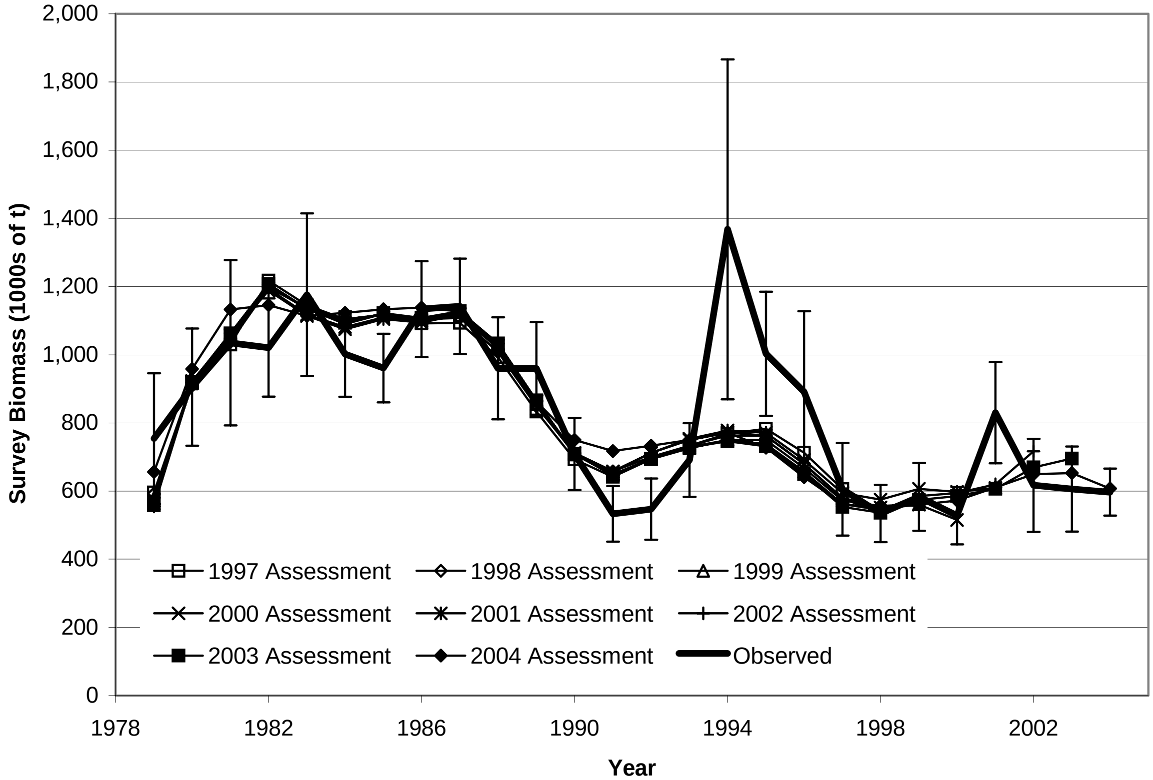


Figure 2.7–Retrospective analysis of estimated survey biomass, 1997-present. The vertical error bars around the observed survey biomass represent 1.96 standard deviations on either side of the mean.

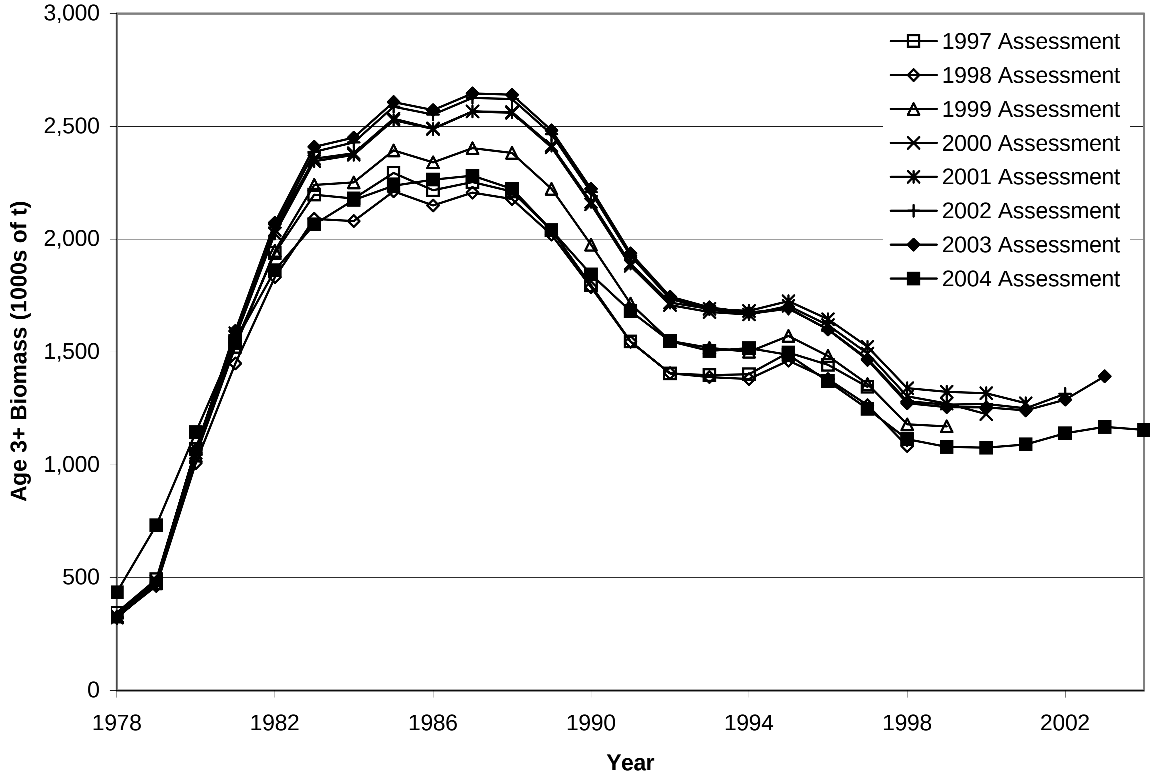


Figure 2.8–Retrospective analysis of estimated age 3+ biomass, 1997-present.

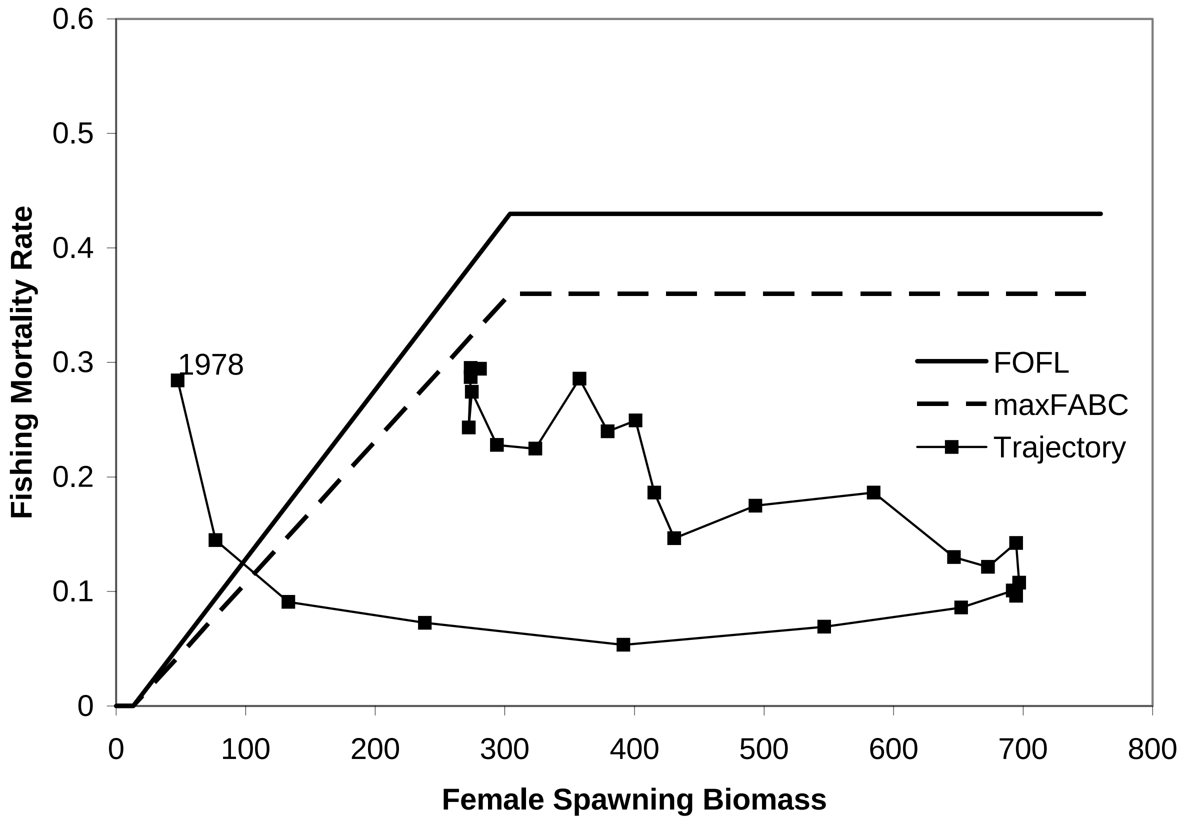


Figure 2.9–Trajectory of fishing mortality and female spawning biomass, 1978-present.

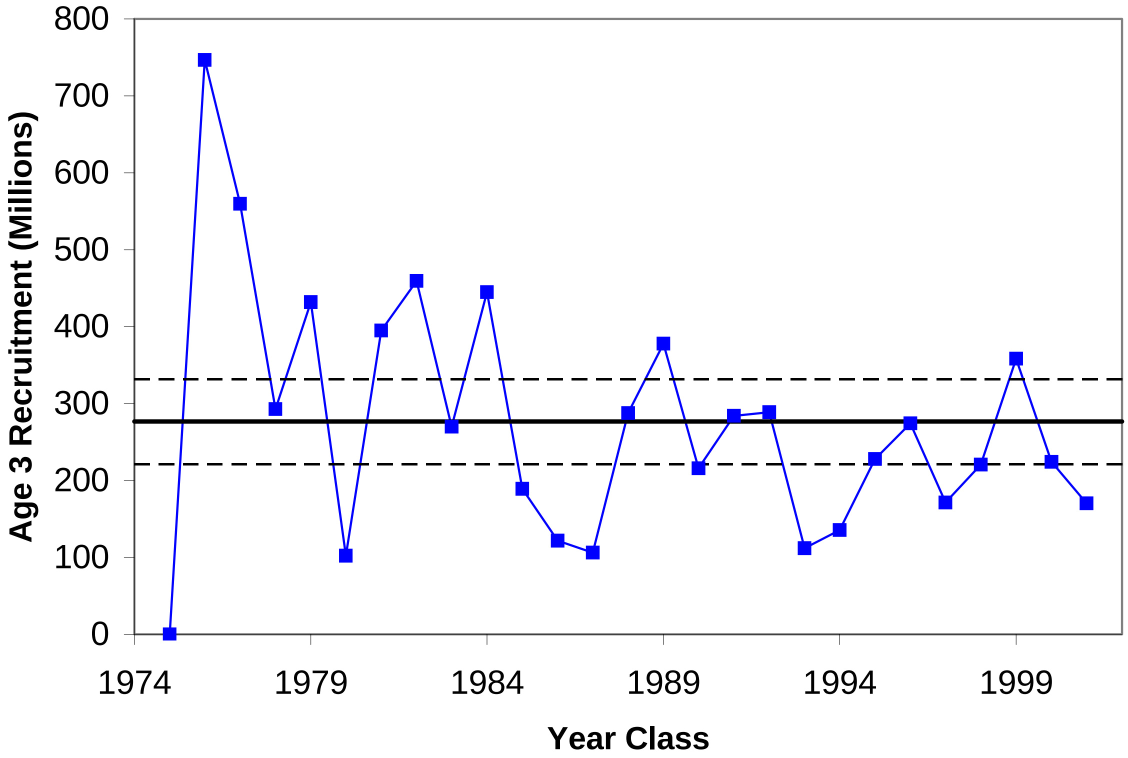


Figure 2.10–Pacific cod recruitment at age 3 (EBS only) as estimated by the stock assessment model. Points represent individual recruitment estimates. The bold horizontal line represents the mean of the time series. The lower and upper dashed horizontal lines represent 80% and 120%, respectively, of the time series mean.

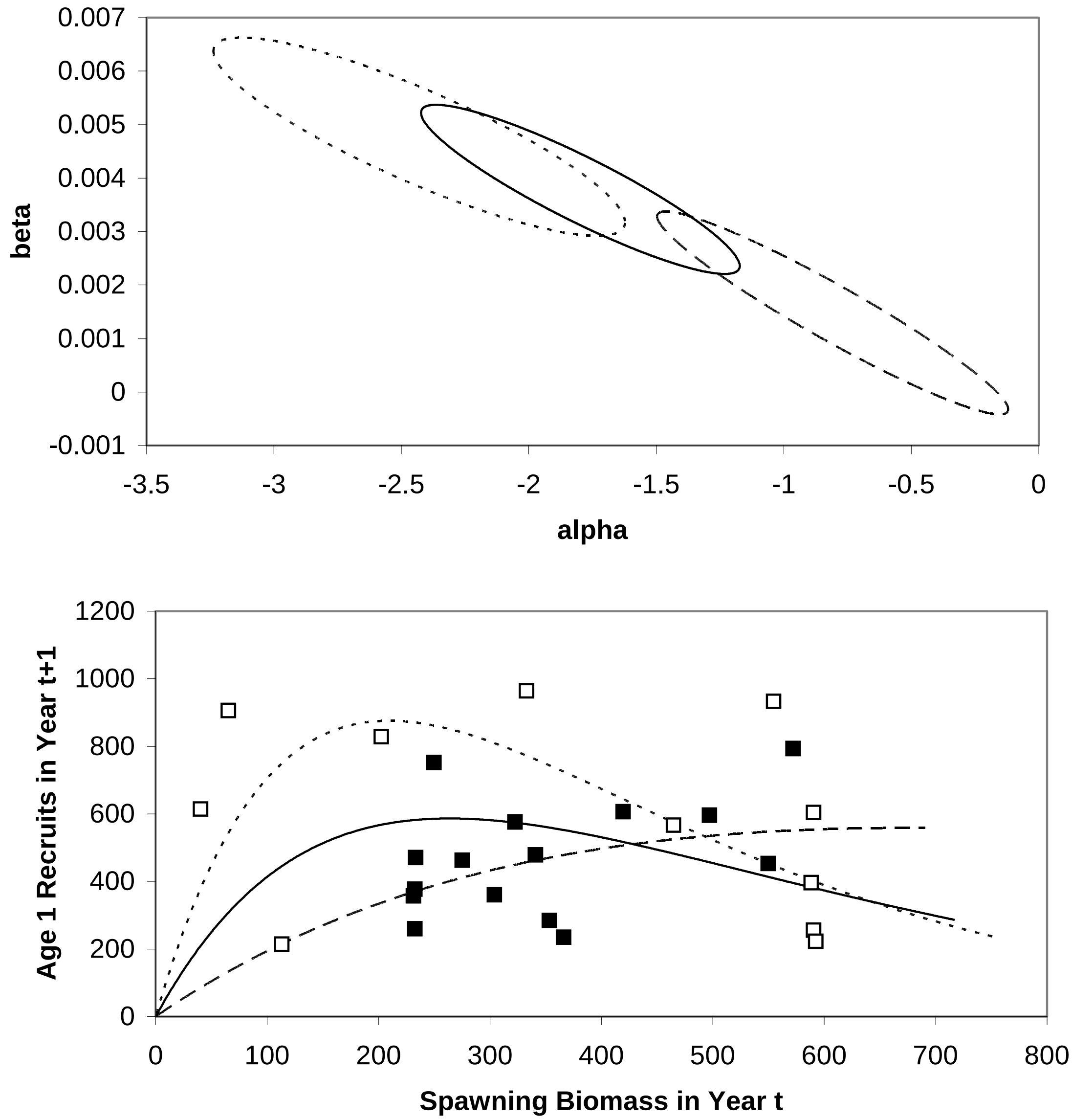


Figure 2.11–Some aspects of uncertainty surrounding the stock-recruitment relationship. The upper panel shows 95% confidence ellipses for the estimated parameters of the stock-recruitment relationship. The dotted, dashed, and solid ellipses correspond to the pre-1989 data subset, the post-1988 data subset, and the entire data set, respectively. The lower panel shows the data (squares) and estimated relationships (curves). The open and solid squares correspond to the pre-1989 data subset and the post-1988 data subset, respectively. The dotted, dashed, and solid curves correspond to the pre-1989 data subset, the post-1988 data subset, and the entire data set, respectively. See text for details and caveats.

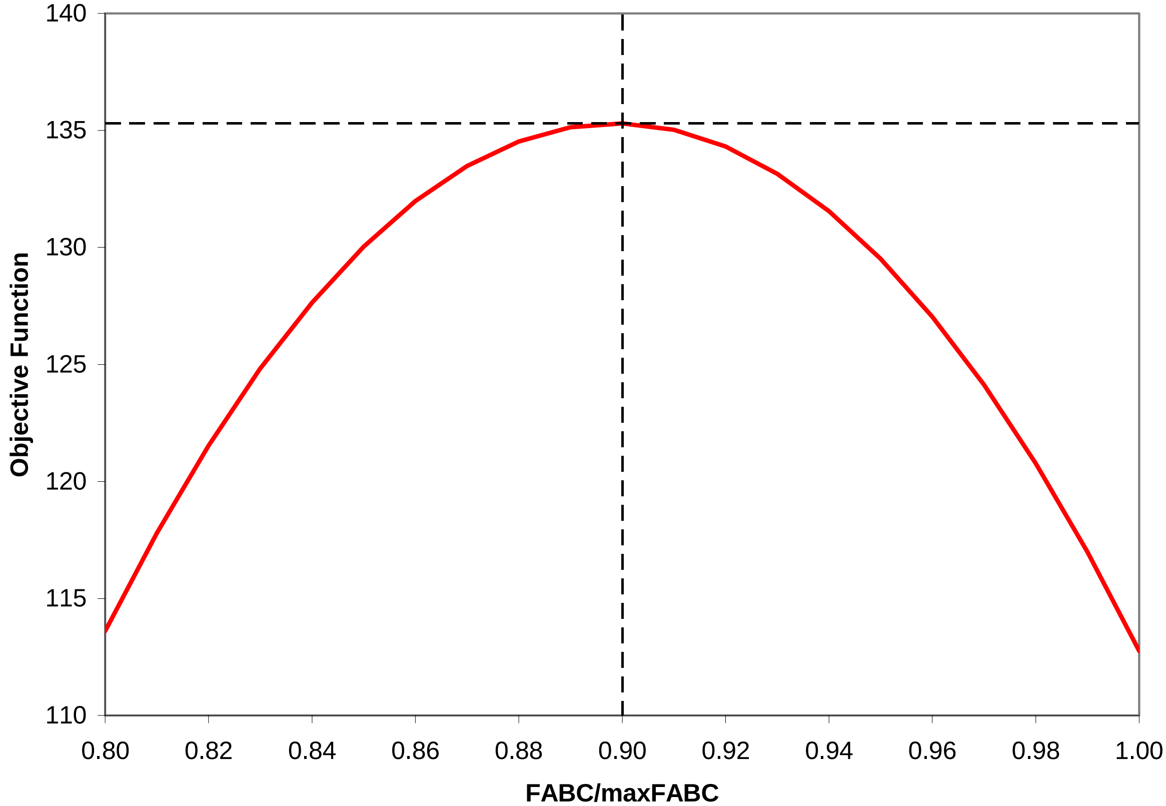


Figure 2.12–Relationship between fishing mortality (expressed as a proportion of the maximum permissible ABC fishing mortality rate, maxFABC) and the objective function used to recommend ABC. The objective function is maximized at a ratio of 0.90. See text for details.

Attachment 2A: Estimation of Pacific Cod Biomass Distributions
Based on Alternative Weightings of Trawl Survey Estimates

INTRODUCTION

Management of the Pacific cod (*Gadus macrocephalus*) stocks in the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) is currently based on spatially aggregated models. However, the acceptable biological catch (ABC) for the GOA stock has traditionally been split among the three GOA regulatory areas (Western, Central, and Eastern) and interest has recently been expressed in doing likewise in the BSAI by splitting the ABC for that stock into Bering Sea (BS) and Aleutian Islands (AI) components. Absent a spatially disaggregated stock assessment model, the ABC split in the GOA has usually approximated the average distribution of the biomass estimates from the most recent bottom trawl surveys. In the BSAI, where no ABC split currently exists, the emphasis has been on identifying the long-term distribution of biomass between the two areas, so a long-term weighted average has been used in the BSAI rather than relying only on the most recent survey biomass estimates as is done in the GOA.

At its December, 2003 meeting, the Scientific and Statistical Committee made the following request: *"The ABC for BS/AI cod is not currently allocated by area. If the ABC were apportioned by the same multiplier used to expand the EBS assessment to the full BS/AI area, the ABC would be 191,000 mt and 32,000 mt for the EBS and AI areas, respectively. The team and authors were concerned that this apportionment may have implications on cod fishery management and allocation. The SSC believes that the ABC should be split among BS and AI areas, but we are not in a position to address the concerns expressed by the authors. Therefore, for the 2005 specification process, the SSC requests the authors to evaluate the methods used to split the ABC and their potential management implications, so that specific recommendations can be made to the Council on this issue in the future."*

This paper attempts to address the above request for an evaluation of alternative methods that could be used to apportion the BSAI Pacific cod ABC between areas. It is assumed that any actual distribution of Pacific cod ABC in the BSAI would be based on the distribution of biomass. Because the methods described here could also be applied to the Pacific cod ABC in the GOA, the distribution of Pacific cod biomass in the GOA is addressed here as well.

DATA AND METHODS

Data

The time series of bottom trawl survey biomass estimates and standard errors are shown in Tables 2A1 (BS and AI) and 2A2 (Western, Central, and Eastern GOA). The Aleutian Islands data cover the entire Aleutian Islands survey area, which includes both the Aleutian Islands management area and the southern portion of the Bering Sea management area that is not assessed by the Bering Sea bottom trawl survey.

General Considerations

Two issues are addressed in this study: First, how do alternative estimators of the *current* distribution of biomass perform and, second, how do alternative estimators of the *average* distribution of biomass perform? The methods presented here are predicated on the assumptions that the time series of bottom trawl biomass estimates by area are the only available information upon which to base an estimate of biomass distribution and that survey catchabilities and selectivities are constant across areas within a region (e.g., survey catchability and selectivity in the BS are equal to those in the AI). All of the methods presented here can be viewed as special cases of the following algorithm: 1) For each area, form an estimate for the biomass in that area by applying a vector of weights to the survey time series for that area; then 2) for each area, form a ratio between the estimated biomass in that area and the sum of the estimated biomasses in that region (BSAI or GOA).

The differences between the methods presented here are as follow: 1) For the estimators of *current* biomass, several alternative weighting vectors were applied to the survey time series, including sets of vectors corresponding to various exponential weighting systems and the vector implied by the Kalman filter. 2) For the estimators of *average* biomass, the weights were all equal to the inverse of the number of observations, but they are applied to two different time series: the survey estimates of biomass and the Kalman filter estimates of biomass.

The first observation in each survey time series is indexed $i=1$ and the terminal observation in each survey time series is indexed $i=n$. Index $i=0$, then, refers to the time period preceding the first observation.

Exponential Weighting Alternatives

For a given exponential rate parameter p, an exponential weighting vector starts with the following weight for index $i=0$:

$$\theta_0 = (1 - p)^n$$

For observations $i=1$ through $i=n$, the weight takes the form

$$\theta_i = p(1 - p)^{n-i}$$

Nine alternative vectors of exponential weights, corresponding to nine different values of the rate parameter p, are shown in Tables 2A3 (BS and AI) and 2A4 (Western, Central, and Eastern GOA).

Under certain special circumstances, the exponential weights described above correspond to the weights that would be implied by the Kalman filter. These circumstances are as follow: 1) the slope coefficients of the transition and observation equations are both unity and the intercept coefficients of the transition and observation equations are both zero (i.e., biomass tends to follow a trendless random walk and the survey tends to be an unbiased estimator of biomass), 2) process error variance is constant over time, 3) measurement error variance is constant over time, 4) observations are evenly spaced in time, 5) the exponential rate parameter is given by

$$p = \frac{2}{\sqrt{4r + 1} + 1}$$

where r is the ratio of measurement error variance to process error variance, and 6) the posterior estimate of the state at index $i=0$ is given by

$$\left(\frac{1-p}{p}\right)\sigma x^2$$

where σx^2 is the process error variance. Meinhold and Singpurwalla (1983) considered the special case of the above in which r=2 (resulting in p=1-p=0.5) and σx^2=1.

Kalman Filter

For the more general case in which conditions (3-6) are relaxed, the Kalman filter weights can be derived from a vector w where, given a value for w_0, elements w_1 through w_n are defined recursively by

$$w_i = \frac{w_{i-1}\sigma y_{i-1}^2 + \tau_i \sigma x^2}{w_{i-1}\sigma y_{i-1}^2 + \tau_i \sigma x^2 + \sigma y_i^2}$$

where σy_i is the standard error of the ith observation and τ_i represents the time elapsed between observation i-1 and observation i (for i=1, σy_{i-1} was set equal to zero and τ_i was set equal to unity). For this study, σx was estimated for each area by the method of maximum likelihood (Harvey 1990).

From the vector w, the Kalman weights ω can be defined recursively by the equations

$$\omega_i = \prod_{j=1}^{n} (1-w_j)$$

for i=0,

$$\omega_i = w_i \prod_{j=i+1}^{n} (1-w_j)$$

for i=1 through i=n-1, and

$$\omega_i = w_n$$

for i=n.

The above formulae are conditional on the value of w_0. If the initial size of the population is viewed as a parameter to be estimated, then the appropriate value of w_0 is zero (Harvey 1990).

The weighting vectors implied by the Kalman filter for the BSAI and GOA are shown in the right-hand column of Tables 2A3 and 2A4, respectively.

Application of Weights

In the Kalman filter, the posterior mean estimate of biomass at the time of the final observation is given by

$$\omega_0 \mu_0 + \sum_{i=1}^{n} \omega_i y_i$$

where μ_0 is the maximum likelihood estimate of the initial biomass (i.e., the biomass prior to the first observation) and y_i is the *i*th survey biomass estimate.

The above implies a potential problem for the exponential weighting alternatives, because it is not obvious how to compute μ_0 for those alternatives. To make the analyses comparable, the value of μ_0 obtained from the Kalman filter was used here for the exponential weighting alternatives as well. This gives the following estimate of current biomass for the exponential weighting alternatives:

$$\theta_0 \mu_0 + \sum_{i=1}^{n} \theta_i y_i$$

where the vector θ is prescribed by the value of p associated with a given exponential weighting alternative.

RESULTS

Parameters

The only parameters estimated in this analysis are the initial biomass (i.e., the biomass preceding the first observation) and the process error standard deviation.

The initial biomass estimates obtained from the Kalman filter are as follow:

Area:	BS	AI	WGOA	CGOA	EGOA
B(ini):	810,420 t	166,611 t	89,010 t	310,679 t	26,141 t

The maximum likelihood estimates of the process error standard deviation obtained from the Kalman filter are as follow:

Area:	BS	AI	WGOA	CGOA	EGOA
σx:	125,103 t	22,886 t	12,850 t	25,846 t	2,208 t

The process error standard deviation can be divided by the initial biomass to give the following coefficients of variation:

Area:	BS	AI	WGOA	CGOA	EGOA
CV:	0.15	0.14	0.14	0.08	0.08

Current Biomass

Time series of biomass estimates and 95% confidence intervals are shown for both the raw survey data and the Kalman filter in Figures 2A1 (BS and AI) and 2A2 (WGOA, CGOA, and EGOA). Absolute and relative 2004 biomass estimates for the BSAI are given in Tables 2A5a and 2A5b, respectively. Absolute and relative 2003 biomass estimates for the GOA are given in Tables 2A6a and 6b, respectively. Current biomass proportions for the BS and AI range from 83% to 85% and 15% to 17%, respectively. Current biomass proportions for the Western, Central, and Eastern GOA range from 27% to 33%, 61% to 68%, and 5% to 6%, respectively.

Average Biomass

The average biomass estimates from the bottom trawl surveys are as follow:

Area:	BS	AI	WGOA	CGOA	EGOA
B(ave):	834,300 t	156,564 t	125,561 t	250,518 t	23,559 t

The average biomass estimates from the Kalman filter are as follow:

Area:	BS	AI	WGOA	CGOA	EGOA
B(ave):	804,214 t	145,481 t	101,784 t	232,464 t	20,442 t

Based on the raw survey data, the distribution of average biomass within each region (BSAI and GOA) is as follows:

Area:	BS	AI	WGOA	CGOA	EGOA
B(ave):	0.84	0.16	0.31	0.63	0.06

Based on the Kalman filter estimates, the distribution of average biomass within each region (BSAI and GOA) is as follows:

Area:	BS	AI	WGOA	CGOA	EGOA
B(ave):	0.85	0.15	0.29	0.65	0.06

DISCUSSION

For the BSAI, all ten of the alternative estimates of current biomass distribution and both of the alternative estimates of average biomass distribution are fairly close to the estimate of average biomass distribution used in last year’s stock assessment (Thompson et al. 2003). Adoption of any of the new alternatives would imply at most a 2% change from the biomass distribution used in last year’s stock assessment, from 85% in the BS down to 83%. Given that the estimates are all so close and given that the assumptions used in this analysis are fairly strong, it is not clear that a compelling case can be made for one of the alternatives over any other. The Kalman filter probably has the strongest theoretical basis, but the exponential weighting alternatives are easier to understand and more predictable from year to year. It is also unclear whether it is necessary to maintain separate estimates for the current distribution of biomass and the average distribution of biomass. On the positive side, maintaining separate estimates would allow the stock assessment to use the average biomass distribution to describe the history of recruitment while allowing area-specific ABCs to be based on the current biomass distribution. On the negative side, maintaining separate estimates could cause confusion for managers and the public. Moreover, in the event that the BSAI ABC is split between the BS and AI areas, it is possible that the area-specific ABCs will be calculated independently of each other, as has been done for some other stocks. For example, the AI portion of the Pacific cod stock might be managed under Tier 5 with a biomass estimate based entirely on the AI survey time series, as opposed to a method in which the AI ABC is set equal to some fraction of the BS ABC.

In the GOA, the new alternative estimates do not bracket the estimate of average biomass distribution upon which the most recent distribution of ABC was based (Thompson and Dorn 2003). At a minimum, the Western ABC allocation would decrease from the current value of 36% down to 33% and the Central ABC allocation would increase from the current value of 57% up to 61%. In the most extreme case, the Western ABC allocation would decrease to 27% and the Central ABC allocation would increase to 68%. (The Eastern GOA would decrease from the current value of 7% down to 5% or 6% under any of the alternatives.) The main reason for the differences in the GOA biomass distribution is that the current formula gives equal weight to each of the last three surveys, while all of the alternatives give greatest weight to the most recent survey which observed a relatively low biomass in the Western area and a relatively high biomass in the Central area.

It should also be noted that considerable effort has recently gone into the development of improved methods for assessing the spatial dynamics of Pacific cod. Although these new methods have yet to be incorporated into the Pacific cod assessments, it is conceivable that more rigorous tools for estimating biomass distributions may be available in the next year or two.

REFERENCES

Harvey, A. C. 1990. *Forecasting, Structural Time Series Models, and the Kalman Filter*. Cambridge University Press. 554 p.

Meinhold, R. J. and N. D. Singpurwalla. 1983. Understanding the Kalman Filter. *American Statistician* 37:123-127.

Thompson, G. G. and M. K. Dorn. 2003. Assessment of the Pacific cod stock in the eastern Bering Sea and Aleutian Islands area. *In* Plan Team for the Groundfish Fisheries of the Bering Sea and Aleutian Islands (compiler), Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, p. 127-222. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Thompson, G. G., H. H. Zenger, and M. W. Dorn. 2003. Assessment of the Pacific cod stock in the Gulf of Alaska. *In* Plan Team for Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 149-241. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Table 2A1a. BS survey biomass estimates (t) with standard errors (t).

Year	Biomass	Std. Error
1979	754,314	97,844
1980	905,344	87,898
1981	1,034,629	123,849
1982	1,020,550	73,392
1983	1,176,305	121,606
1984	1,001,940	64,127
1985	961,050	51,453
1986	1,134,106	71,813
1987	1,142,450	71,439
1988	959,544	76,284
1989	960,436	69,157
1990	708,551	53,728
1991	532,590	41,678
1992	546,707	45,754
1993	690,524	54,934
1994	1,368,109	254,435
1995	1,003,046	92,677
1996	890,793	120,522
1997	604,881	69,250
1998	534,141	42,942
1999	583,259	50,622
2000	528,466	43,037
2001	830,479	75,675
2002	616,923	69,586
2003	605,681	63,601
2004	596,988	35,135

Table 2A1b. AI survey biomass estimates (t) with standard errors (t).

Year	Biomass	Std. Error
1980	148,272	29,778
1983	215,755	30,993
1986	255,007	66,524
1991	189,190	25,532
1994	184,109	33,695
1997	83,416	10,499
2000	136,075	23,553
2002	82,853	12,018
2004	114,396	19,973

Table 2A2a. Western GOA survey biomass estimates (t) with standard errors (t).

Year	Biomass	Std. Error
1984	173,843	58,375
1987	72,312	6,877
1990	129,744	19,689
1993	120,122	10,960
1996	188,128	57,438
1999	112,076	19,395
2001	133,214	44,689
2003	75,052	18,546

Table 2A2b. Central GOA survey biomass estimates (t) with standard errors (t).

Year	Biomass	Std. Error
1984	340,336	53,505
1987	289,790	49,463
1990	262,732	60,531
1993	269,258	72,487
1996	337,388	91,105
1999	172,620	33,108
2001	124,400	27,470
2003	207,619	40,438

Table 2A2c. Eastern GOA survey biomass estimates (t) with standard errors (t). Note that the Western and Central GOA were surveyed in 2001, but the Eastern GOA was not.

Year	Biomass	Std. Error
1984	36,792	13,830
1987	32,886	11,848
1990	25,725	3,643
1993	20,468	4,185
1996	12,638	2,789
1999	21,718	5,032
2003	14,689	2,608

Table 2A3a. Alternative schedules of weights for the Bering Sea survey time series. The first column shows the year of the survey. The next nine columns show alternative schedules of exponential weights. The right-hand column shows the weights implied by the Kalman filter.

Year	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
1978	0.0646	0.0030	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1979	0.0072	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1980	0.0080	0.0009	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1981	0.0089	0.0012	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1982	0.0098	0.0015	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1983	0.0109	0.0018	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1984	0.0122	0.0023	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1985	0.0135	0.0029	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1986	0.0150	0.0036	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1987	0.0167	0.0045	0.0007	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1988	0.0185	0.0056	0.0010	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1989	0.0206	0.0070	0.0014	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1990	0.0229	0.0088	0.0020	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1991	0.0254	0.0110	0.0029	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
1992	0.0282	0.0137	0.0042	0.0009	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
1993	0.0314	0.0172	0.0059	0.0015	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
1994	0.0349	0.0215	0.0085	0.0024	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000
1995	0.0387	0.0268	0.0121	0.0040	0.0010	0.0002	0.0000	0.0000	0.0000	0.0000
1996	0.0430	0.0336	0.0173	0.0067	0.0020	0.0004	0.0000	0.0000	0.0000	0.0000
1997	0.0478	0.0419	0.0247	0.0112	0.0039	0.0010	0.0002	0.0000	0.0000	0.0000
1998	0.0531	0.0524	0.0353	0.0187	0.0078	0.0025	0.0005	0.0001	0.0000	0.0000
1999	0.0590	0.0655	0.0504	0.0311	0.0156	0.0061	0.0017	0.0003	0.0000	0.0000
2000	0.0656	0.0819	0.0720	0.0518	0.0313	0.0154	0.0057	0.0013	0.0001	0.0005
2001	0.0729	0.1024	0.1029	0.0864	0.0625	0.0384	0.0189	0.0064	0.0009	0.0015
2002	0.0810	0.1280	0.1470	0.1440	0.1250	0.0960	0.0630	0.0320	0.0090	0.0084
2003	0.0900	0.1600	0.2100	0.2400	0.2500	0.2400	0.2100	0.1600	0.0900	0.0505
2004	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	0.9390

Table 2A3b. Alternative schedules of weights for the Aleutian Island survey time series. The first column shows the year of the survey. The next nine columns show alternative schedules of exponential weights. The right-hand column shows the weights implied by the Kalman filter.

Year	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
1979	0.3874	0.1342	0.0404	0.0101	0.0020	0.0003	0.0000	0.0000	0.0000	0.0000
1980	0.0430	0.0336	0.0173	0.0067	0.0020	0.0004	0.0000	0.0000	0.0000	0.0000
1983	0.0478	0.0419	0.0247	0.0112	0.0039	0.0010	0.0002	0.0000	0.0000	0.0000
1986	0.0531	0.0524	0.0353	0.0187	0.0078	0.0025	0.0005	0.0001	0.0000	0.0000
1991	0.0590	0.0655	0.0504	0.0311	0.0156	0.0061	0.0017	0.0003	0.0000	0.0001
1994	0.0656	0.0819	0.0720	0.0518	0.0313	0.0154	0.0057	0.0013	0.0001	0.0002
1997	0.0729	0.1024	0.1029	0.0864	0.0625	0.0384	0.0189	0.0064	0.0009	0.0054
2000	0.0810	0.1280	0.1470	0.1440	0.1250	0.0960	0.0630	0.0320	0.0090	0.0171
2002	0.0900	0.1600	0.2100	0.2400	0.2500	0.2400	0.2100	0.1600	0.0900	0.2301
2004	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	0.7472

Table 2A4a. Alternative schedules of weights for the Western GOA survey time series. The first column shows the year of the survey. The next nine columns show alternative schedules of exponential weights. The right-hand column shows the weights implied by the Kalman filter.

Year	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
1983	0.4305	0.1678	0.0577	0.0168	0.0039	0.0007	0.0001	0.0000	0.0000	0.0002
1984	0.0478	0.0419	0.0247	0.0112	0.0039	0.0010	0.0002	0.0000	0.0000	0.0000
1987	0.0531	0.0524	0.0353	0.0187	0.0078	0.0025	0.0005	0.0001	0.0000	0.0030
1990	0.0591	0.0655	0.0504	0.0311	0.0156	0.0061	0.0017	0.0003	0.0000	0.0045
1993	0.0656	0.0819	0.0720	0.0518	0.0313	0.0154	0.0057	0.0013	0.0001	0.0460
1996	0.0729	0.1024	0.1029	0.0864	0.0625	0.0384	0.0189	0.0064	0.0009	0.0097
1999	0.0810	0.1280	0.1470	0.1440	0.1250	0.0960	0.0630	0.0320	0.0090	0.1688
2001	0.0900	0.1600	0.2100	0.2400	0.2500	0.2400	0.2100	0.1600	0.0900	0.0702
2003	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	0.6977

Table 2A4b. Alternative schedules of weights for the Central GOA survey time series. The first column shows the year of the survey. The next nine columns show alternative schedules of exponential weights. The right-hand column shows the weights implied by the Kalman filter.

Year	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
1983	0.4305	0.1678	0.0577	0.0168	0.0039	0.0007	0.0001	0.0000	0.0000	0.0018
1984	0.0478	0.0419	0.0247	0.0112	0.0039	0.0010	0.0002	0.0000	0.0000	0.0004
1987	0.0531	0.0524	0.0353	0.0187	0.0078	0.0025	0.0005	0.0001	0.0000	0.0023
1990	0.0591	0.0655	0.0504	0.0311	0.0156	0.0061	0.0017	0.0003	0.0000	0.0040
1993	0.0656	0.0819	0.0720	0.0518	0.0313	0.0154	0.0057	0.0013	0.0001	0.0060
1996	0.0729	0.1024	0.1029	0.0864	0.0625	0.0384	0.0189	0.0064	0.0009	0.0073
1999	0.0810	0.1280	0.1470	0.1440	0.1250	0.0960	0.0630	0.0320	0.0090	0.0952
2001	0.0900	0.1600	0.2100	0.2400	0.2500	0.2400	0.2100	0.1600	0.0900	0.3455
2003	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	0.5374

Table 2A4c. Alternative schedules of weights for the Eastern GOA survey time series. The first column shows the year of the survey. The next nine columns show alternative schedules of exponential weights. The right-hand column shows the weights implied by the Kalman filter. Note that while the Western and Central portions of the GOA were surveyed in 2001, the Eastern portion was not.

Year	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
1983	0.4783	0.2097	0.0824	0.0280	0.0078	0.0016	0.0002	0.0000	0.0000	0.0025
1984	0.0531	0.0524	0.0353	0.0187	0.0078	0.0025	0.0005	0.0001	0.0000	0.0001
1987	0.0591	0.0655	0.0504	0.0311	0.0156	0.0061	0.0017	0.0003	0.0000	0.0004
1990	0.0656	0.0819	0.0720	0.0518	0.0313	0.0154	0.0057	0.0013	0.0001	0.0071
1993	0.0729	0.1024	0.1029	0.0864	0.0625	0.0384	0.0189	0.0064	0.0009	0.0138
1996	0.0810	0.1280	0.1470	0.1440	0.1250	0.0960	0.0630	0.0320	0.0090	0.0759
1999	0.0900	0.1600	0.2100	0.2400	0.2500	0.2400	0.2100	0.1600	0.0900	0.0809
2003	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	0.8193

Table 2A5a. Absolute 2004 biomass estimates for BS and AI Pacific cod. The first column shows the area to which the biomass estimates in that row pertain. The next nine columns show 2004 biomass estimates for alternative exponential weighting schemes. The right-hand column shows the 2004 biomass estimate implied by the Kalman filter.

Area	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
BS	738,803	668,109	637,007	622,817	614,806	608,901	604,062	600,418	598,154	597,921
AI	154,053	139,332	126,724	117,724	112,294	109,720	109,165	109,961	111,731	107,359

Table 2A5b. Relative 2004 biomass estimates for BS and AI Pacific cod (column entries sum to 1.0). The first column shows the area to which the biomass estimates in that row pertain. The next nine columns show relative 2004 biomass estimates for alternative exponential weighting schemes. The right-hand column shows the relative 2004 biomass estimate implied by the Kalman filter.

Area	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
BS	0.8275	0.8274	0.8341	0.8410	0.8456	0.8473	0.8469	0.8452	0.8426	0.8478
AI	0.1725	0.1726	0.1659	0.1590	0.1544	0.1527	0.1531	0.1548	0.1574	0.1522

Table 2A6a. Absolute 2003 biomass estimates for Western, Central, and Eastern GOA Pacific cod. The first column shows the area to which the biomass estimates in that row pertain. The next nine columns show 2003 biomass estimates for alternative exponential weighting schemes. The right-hand column shows the 2003 biomass estimate implied by the Kalman filter.

Area	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
WGOA	108,303	114,294	113,497	109,439	103,970	98,035	92,099	86,339	80,726	88,794
CGOA	269,132	238,939	217,690	203,479	194,900	190,955	190,903	194,113	199,937	177,497
EGOA	24,027	21,800	19,894	18,451	17,442	16,755	16,252	15,805	15,310	15,297

Table 2A6b. Relative 2003 biomass estimates for Western, Central, and Eastern GOA Pacific cod (column entries sum to 1.0). The first column shows the area to which the biomass estimates in that row pertain. The next nine columns show relative 2003 biomass estimates for alternative exponential weighting schemes. The right-hand column shows the relative 2003 biomass estimate implied by the Kalman filter.

Area	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
WGOA	0.2698	0.3048	0.3233	0.3303	0.3287	0.3206	0.3078	0.2914	0.2727	0.3153
CGOA	0.6704	0.6371	0.6201	0.6141	0.6162	0.6246	0.6379	0.6552	0.6755	0.6303
EGOA	0.0598	0.0581	0.0567	0.0557	0.0551	0.0548	0.0543	0.0533	0.0517	0.0543

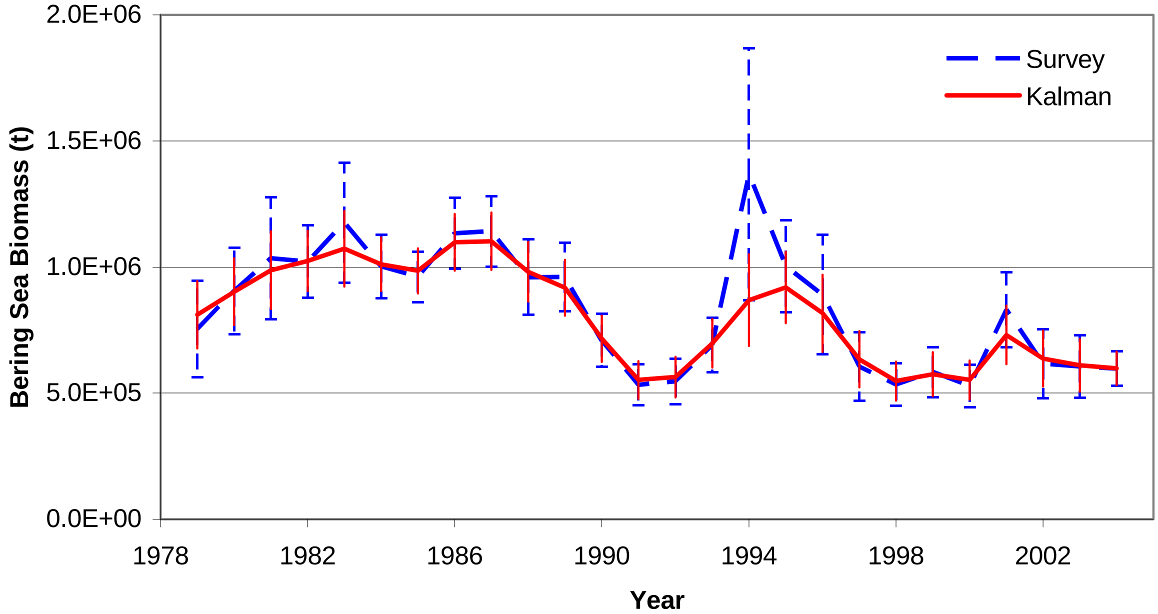


Figure 2A1a. BS biomass estimates with 95% confidence intervals.

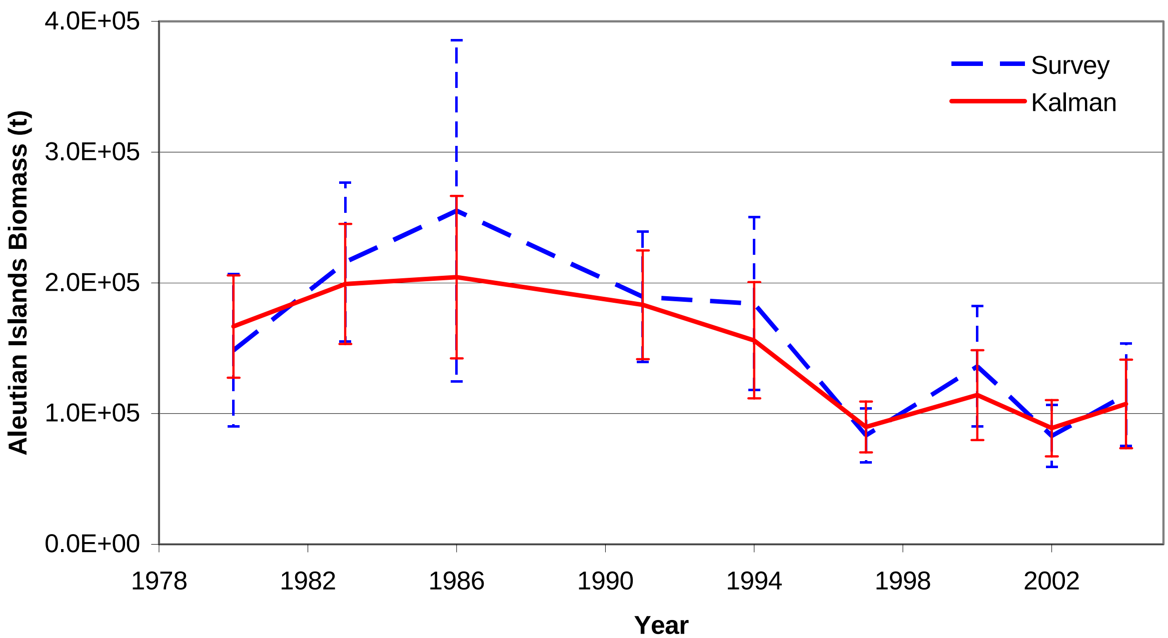


Figure 2A1b. AI biomass estimates with 95% confidence intervals.

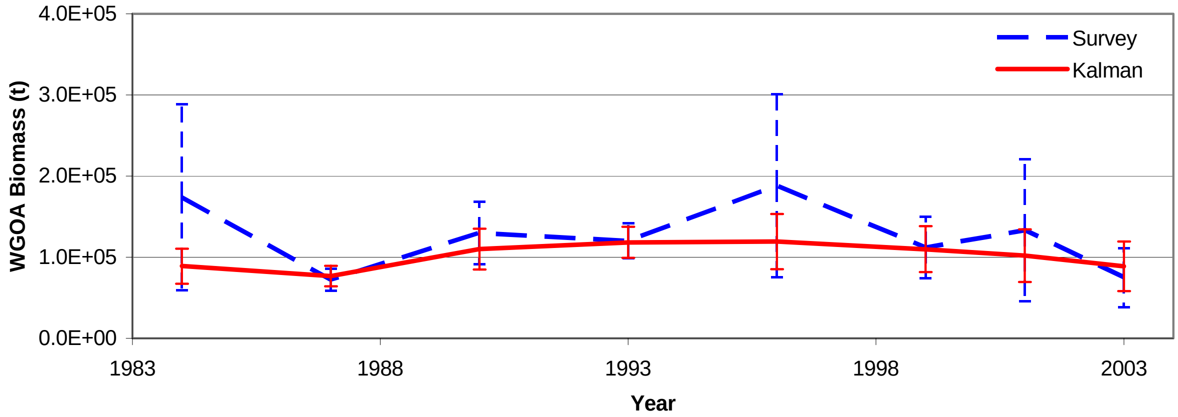


Fig. 2A2a. Western GOA biomass estimates with 95% confidence intervals.

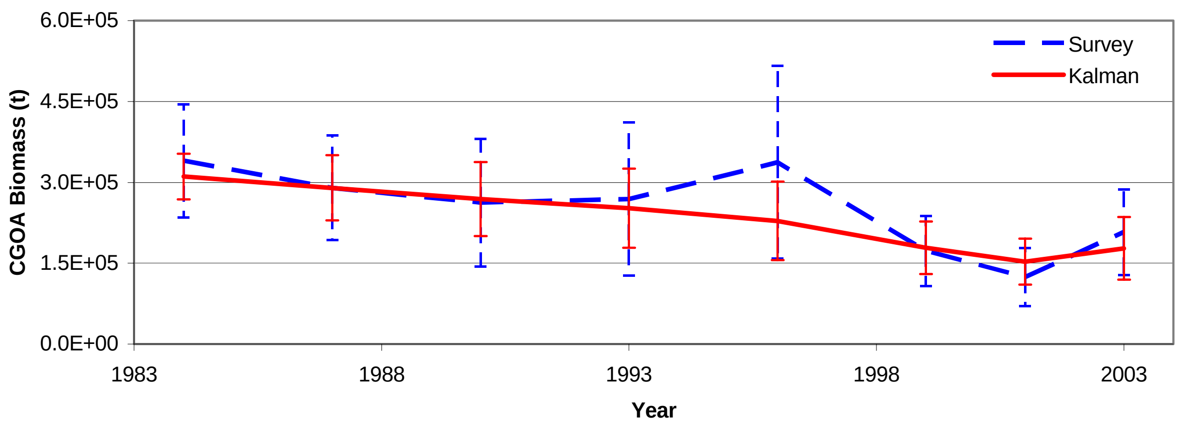


Fig. 2A2b. Central GOA biomass estimates with 95% confidence intervals.

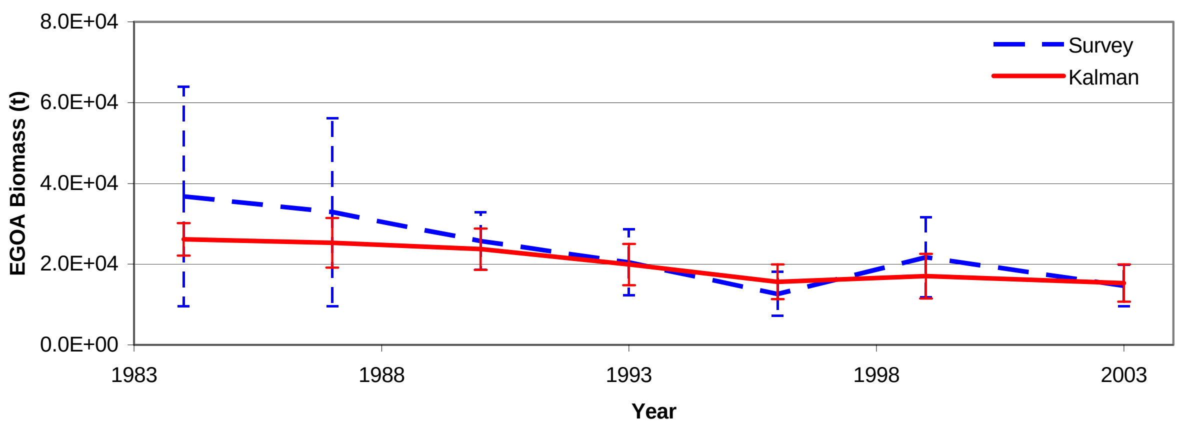


Fig. 2A2c. Eastern GOA biomass estimates with 95% confidence intervals.

Attachment 2B: Standard Harvest Scenarios and Projections Under Model 1

The following seven tables show the results of the standard harvest scenarios using the standard projection model and the results from Model 1.

Table 2B1–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	949	0	0
40%	380	0.32	292
35%	333	0.38	313

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	388	388	388	388	0.00
2006	363	363	363	363	0.14
2007	332	335	336	341	2.88
2008	306	320	324	353	15.48
2009	287	325	331	394	35.30
2010	282	341	348	438	50.75
2011	287	357	365	472	59.59
2012	292	367	377	489	64.11
2013	298	373	383	506	66.13
2014	300	376	387	518	67.11
2015	301	375	389	515	67.88
2016	301	377	390	516	68.16
2017	304	378	391	519	67.68

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.32	0.32	0.32	0.32	0.000
2006	0.30	0.30	0.30	0.30	0.000
2007	0.28	0.28	0.28	0.28	0.003
2008	0.25	0.27	0.27	0.29	0.013
2009	0.24	0.27	0.27	0.32	0.025
2010	0.23	0.28	0.28	0.32	0.029
2011	0.24	0.30	0.29	0.32	0.029
2012	0.24	0.31	0.30	0.32	0.027
2013	0.25	0.31	0.30	0.32	0.026
2014	0.25	0.31	0.30	0.32	0.026
2015	0.25	0.31	0.30	0.32	0.025
2016	0.25	0.32	0.30	0.32	0.024
2017	0.25	0.32	0.30	0.32	0.024

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	280	280	280	280	0.01
2006	242	242	243	244	0.79
2007	198	208	211	233	11.45
2008	167	200	209	277	36.48
2009	153	218	228	337	58.68
2010	154	242	250	367	68.22
2011	162	261	266	379	70.94
2012	167	272	275	389	70.66
2013	169	278	279	400	70.73
2014	173	280	281	398	70.49
2015	176	282	283	399	70.31
2016	175	283	284	402	69.42
2017	179	284	285	406	69.25

Table 2B2–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that the ratio of F to $max\ F_{ABC}$ in 2005-2017 is fixed at a value of 0.78, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	949	0	0
40%	380	0.32	292
35%	333	0.38	313

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	391	391	391	391	0.00
2006	383	383	383	383	0.14
2007	361	364	365	370	2.91
2008	337	352	356	386	15.92
2009	318	357	364	431	37.75
2010	312	375	384	486	56.92
2011	316	393	405	530	69.34
2012	322	408	421	554	76.35
2013	326	418	432	577	79.87
2014	330	427	439	595	81.74
2015	334	431	443	595	82.94
2016	335	434	447	589	83.36
2017	338	437	449	598	82.90

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.25	0.25	0.25	0.25	0.000
2006	0.25	0.25	0.25	0.25	0.000
2007	0.23	0.24	0.24	0.24	0.002
2008	0.22	0.23	0.23	0.25	0.009
2009	0.20	0.23	0.23	0.25	0.015
2010	0.20	0.24	0.23	0.25	0.017
2011	0.20	0.25	0.24	0.25	0.016
2012	0.21	0.25	0.24	0.25	0.014
2013	0.21	0.25	0.24	0.25	0.014
2014	0.21	0.25	0.24	0.25	0.013
2015	0.21	0.25	0.24	0.25	0.012
2016	0.22	0.25	0.24	0.25	0.011
2017	0.22	0.25	0.24	0.25	0.011

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	223	223	223	223	0.00
2006	210	210	210	211	0.62
2007	181	190	192	210	9.72
2008	157	185	192	249	29.67
2009	144	200	206	284	45.79
2010	143	220	222	314	53.38
2011	149	234	235	325	55.82
2012	155	242	244	336	56.11
2013	158	247	248	347	56.36
2014	163	250	251	346	56.28
2015	167	250	254	346	56.00
2016	168	252	255	349	55.22
2017	169	252	257	356	54.87

Table 2B3–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that F = ½ *max* F_{ABC} in 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	949	0	0
40%	380	0.32	292
35%	333	0.38	313

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	396	396	396	396	0.00
2006	411	411	412	412	0.15
2007	409	412	412	418	3.03
2008	394	410	414	447	17.13
2009	376	421	428	506	42.88
2010	367	444	454	575	67.67
2011	371	470	483	635	84.96
2012	380	494	507	668	95.14
2013	383	514	525	700	100.42
2014	392	526	538	725	103.19
2015	398	534	547	737	104.67
2016	410	542	555	737	105.09
2017	413	549	559	741	104.39

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.21	0.21	0.21	0.21	0.000
2006	0.21	0.21	0.21	0.21	0.000
2007	0.21	0.21	0.21	0.21	0.000
2008	0.21	0.21	0.21	0.21	0.000
2009	0.21	0.21	0.21	0.21	0.000
2010	0.21	0.21	0.21	0.21	0.000
2011	0.21	0.21	0.21	0.21	0.000
2012	0.21	0.21	0.21	0.21	0.000
2013	0.21	0.21	0.21	0.21	0.000
2014	0.21	0.21	0.21	0.21	0.000
2015	0.21	0.21	0.21	0.21	0.000
2016	0.21	0.21	0.21	0.21	0.000
2017	0.21	0.21	0.21	0.21	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	192	192	192	192	0.00
2006	184	184	184	185	0.48
2007	171	177	179	193	7.27
2008	159	180	184	222	20.75
2009	153	190	195	253	32.57
2010	153	201	207	278	40.01
2011	157	210	216	292	43.81
2012	160	217	223	303	45.42
2013	162	222	227	313	46.22
2014	164	225	230	315	46.70
2015	168	226	233	312	46.77
2016	170	229	234	316	46.32
2017	170	230	236	322	46.06

Table 2B4–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that *F* = the 1999-2003 average in 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	949	0	0
40%	380	0.32	292
35%	333	0.38	313

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	393	393	393	393	0.00
2006	395	395	395	395	0.15
2007	381	383	384	390	3.02
2008	358	373	377	409	16.90
2009	334	378	385	460	41.43
2010	322	396	406	519	64.12
2011	323	417	429	570	79.21
2012	329	437	448	598	87.58
2013	333	452	462	621	91.54
2014	340	461	472	642	93.45
2015	346	469	479	647	94.38
2016	355	473	484	646	94.48
2017	357	477	488	654	93.68

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.21	0.21	0.21	0.21	0.000
2006	0.21	0.21	0.21	0.21	0.000
2007	0.21	0.21	0.21	0.21	0.000
2008	0.21	0.21	0.21	0.21	0.000
2009	0.21	0.21	0.21	0.21	0.000
2010	0.21	0.21	0.21	0.21	0.000
2011	0.21	0.21	0.21	0.21	0.000
2012	0.21	0.21	0.21	0.21	0.000
2013	0.21	0.21	0.21	0.21	0.000
2014	0.21	0.21	0.21	0.21	0.000
2015	0.21	0.21	0.21	0.21	0.000
2016	0.21	0.21	0.21	0.21	0.000
2017	0.21	0.21	0.21	0.21	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	192	192	192	192	0.00
2006	184	184	184	185	0.48
2007	171	177	179	193	7.27
2008	159	180	184	222	20.75
2009	153	190	195	253	32.57
2010	153	201	207	278	40.01
2011	157	210	216	292	43.81
2012	160	217	223	303	45.42
2013	162	222	227	313	46.22
2014	164	225	230	315	46.70
2015	168	226	233	312	46.77
2016	170	229	234	316	46.32
2017	170	230	236	322	46.06

Table 2B5–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = 0$ in 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	949	0	0
40%	380	0.32	292
35%	333	0.38	313

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	404	404	404	404	0.00
2006	468	468	468	468	0.15
2007	513	516	517	523	3.05
2008	539	555	559	593	17.88
2009	549	598	607	694	47.95
2010	558	651	663	808	81.80
2011	576	705	722	916	109.98
2012	597	756	774	996	129.91
2013	614	795	815	1061	142.61
2014	632	833	849	1118	150.50
2015	651	857	874	1154	155.25
2016	671	877	895	1177	157.78
2017	691	895	910	1183	157.99

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0	0	0	0	0
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0	0	0	0	0
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0

Table 2B6–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = F_{OFL}$ in 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points					
SPR	Spawning Biomass	Fishing Mortality	Catch		
100%	949	0	0		
40%	380	0.32	292		
35%	333	0.38	313		
Spawning Biomass Projections					
Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	385	385	385	385	0.00
2006	346	346	346	347	0.14
2007	311	314	314	320	2.86
2008	284	298	301	331	15.24
2009	266	303	309	370	33.92
2010	262	319	325	409	46.98
2011	267	334	340	432	53.29
2012	274	341	349	442	55.92
2013	278	346	353	458	56.67
2014	279	346	354	463	56.96
2015	281	345	355	460	57.35
2016	280	346	356	462	57.49
2017	282	347	356	467	56.91
Fishing Mortality Projections					
Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.38	0.38	0.38	0.38	0.000
2006	0.34	0.34	0.34	0.34	0.000
2007	0.31	0.31	0.31	0.32	0.003
2008	0.28	0.29	0.30	0.33	0.016
2009	0.26	0.30	0.30	0.37	0.032
2010	0.26	0.31	0.32	0.38	0.039
2011	0.26	0.33	0.33	0.38	0.039
2012	0.27	0.34	0.33	0.38	0.038
2013	0.27	0.34	0.34	0.38	0.038
2014	0.27	0.34	0.34	0.38	0.037
2015	0.28	0.34	0.34	0.38	0.036
2016	0.27	0.34	0.34	0.38	0.036
2017	0.28	0.34	0.34	0.38	0.036
Catch Projections					
Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	328	328	328	328	0.01
2006	261	262	262	264	0.89
2007	207	218	221	245	12.67
2008	173	209	218	292	40.31
2009	158	228	240	369	66.97
2010	161	254	266	410	78.74
2011	170	274	285	420	82.07
2012	174	283	294	433	81.97
2013	177	291	297	439	81.74
2014	181	290	298	439	81.51
2015	181	290	299	442	81.38
2016	182	291	300	443	80.63
2017	183	292	301	441	80.59

Table 2B7–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in each year 2005-2006 and $F = F_{OFL}$ thereafter, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2003. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	949	0	0
40%	380	0.32	292
35%	333	0.38	313

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	388	388	388	388	0.00
2006	363	363	363	363	0.14
2007	330	333	334	339	2.85
2008	294	308	312	341	15.14
2009	271	307	313	374	33.62
2010	264	320	327	410	46.72
2011	268	334	340	432	53.16
2012	274	341	349	442	55.87
2013	278	346	353	457	56.64
2014	279	346	354	462	56.93
2015	281	345	355	460	57.34
2016	280	346	356	462	57.48
2017	282	347	356	467	56.91

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.32	0.32	0.32	0.32	0.000
2006	0.30	0.30	0.30	0.30	0.000
2007	0.33	0.33	0.33	0.34	0.003
2008	0.29	0.30	0.31	0.34	0.016
2009	0.26	0.30	0.31	0.37	0.031
2010	0.26	0.32	0.32	0.38	0.038
2011	0.26	0.33	0.33	0.38	0.039
2012	0.27	0.34	0.33	0.38	0.038
2013	0.27	0.34	0.34	0.38	0.038
2014	0.27	0.34	0.34	0.38	0.037
2015	0.28	0.34	0.34	0.38	0.036
2016	0.27	0.34	0.34	0.38	0.036
2017	0.28	0.34	0.34	0.38	0.036

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	280	280	280	280	0.01
2006	242	242	243	244	0.79
2007	231	243	246	271	13.42
2008	184	221	230	306	41.20
2009	163	233	245	374	66.69
2010	163	256	268	410	78.32
2011	170	273	285	420	81.89
2012	174	282	293	433	81.95
2013	177	291	297	438	81.76
2014	181	289	298	438	81.53
2015	181	290	299	442	81.39
2016	182	291	300	443	80.64
2017	183	292	301	441	80.59